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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Symposia on Production of Metal Powders, Compacting and Sintering, Cermets

The Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals was formed in 1957 with the aim of facilitating the study of the science, technology and practice of powder metallurgy. It is planned that the Group shall meet twice a year: in spring, for a Symposium or Informal Discussion on a subject related to the industrial aspects of powder metallurgy, and in winter, when papers on original research will be discussed. The papers presented, and discussion to which they give rise, will be printed, together with any other papers accepted by the Group, in a new publication, *Powder Metallurgy*, which will be issued twice yearly.

The proceedings of the first three meetings of the Group are contained in *Powder Metallurgy*, 1958, No. 1/2; 272 pp.

Papers of general or specific interest to nickel or nickel-containing materials are referred to below.

I. JENKINS: 'Recent Developments in Powder Metallurgy', pp. 3–12.

This paper, which was given as the introductory lecture at the Inaugural Meeting of the Group on December 4, 1957, reviews progress in the field of powder metallurgy since the previous symposium, held by the two Institutes in 1944. With the qualification that 'there has been no major technical development in this period to stimulate a greater value of production', the author surveys the materials and processes in current use in the industry, and considers the progress which has been made in investigation of the fundamental principles on which all technological developments are ultimately based. The need for further research is emphasized, and the significance of such work is briefly discussed in connexion with study of sintering, the susceptibility of sintered materials to intergranular fracture, bonding of hard metals, and the strengthening achieved by dispersal of hard particles throughout a metallic matrix.

SYMPOSIUM ON DEVELOPMENTS IN THE PRODUCTION AND QUALITY OF METAL POWDERS, Dec. 4, 1957; pp. 13–72; Disc., pp. 73–8.

J. F. WATKINSON: 'Atomization of Metal and Alloy Powders', pp. 13–23.

The B.S.A. Group have for many years produced porous components from austenitic stainless-steel powder obtained by electrolytic disintegration of unstabilized stainless-steel stock. The advantages offered by other grades of stainless-steel powder were appreciated, but these were not easily produced by the same method. Atomization, however, appeared to hold considerable promise of successful adaptation to production of a range of stainless-steel and alloy powders, and with the aim of exploiting the potential usefulness of this process, the B.S.A. Company, Ltd., obtained, in 1954, a licence for the application, to high-melting materials, of the atomization process developed by Messrs. F. W. Berk and Powder Metallurgy, Ltd. Experimental work in this connexion started in 1955. The paper describes the process in its present stage of development and indicates some of the results obtained with powders so produced.

In introduction, reference is made to two processes, developed in Germany during the war, in which atomization was effected by means of contact with a spinning disc or a jet of air. These techniques proved unsuitable, however, for use with stainless steels, because of formation of stable oxides. In the B.S.A. process a stream of the liquid metal is shattered into powder by a high-velocity water jet. Size-distribution and shape of the powders are extremely suitable for powder-metallurgy purposes, but deleterious oxidation of stainless steels and nickel-base high-temperature alloys can be prevented only by use of an inert atmosphere (nitrogen or argon) during atomization.

Stainless steels which have already been atomized include those of 18–8 type containing 0·5 and 2 per cent. silicon (addition of silicon or boron aids in mitigating oxidation difficulties), niobium-stabilized 18–8 grades, with and without molybdenum or silicon, and those of straight-chromium type. Alloy powders have been successfully produced from 'Nichrome', materials of 'Nimonic' type, 'Kanthal', 'Stellite', 'Permalloy' and cobalt-base materials. High-speed-steel powder has also been produced. Data on the relation between water-pressure and size-distribution are given and mechanical properties typical of green and sintered stainless-steel atomized powders are tabulated. The properties of sintered precipitation-hardened stainless steels, high-speed steels and 'Nimonic'-type alloys are claimed to approach those of the corresponding wrought material.

The paper closes with a discussion of the limitations of the process, and a brief description of a ring-shaped atomizer of the injector type, of which details had been given by Russian investigators.

I. LJUNGBERG: 'Electrolytic Production of Straight and Alloyed Metal Powder', pp. 24–32.

The paper is divided into three sections, covering electrolytic production of iron, nickel, and ferro-alloy powders.

The techniques reviewed are considered in the light of investigations carried out by Husqvarna Vapenfabriks A.B. The subject matter of the first section is, for example, associated with work on the development of electrolytic processes for the production of iron powder suitable for use in high-quality sintered machine parts. The powders can be produced in two ways: by direct precipitation on the cathode, and by deposition of a brittle coating which may be subsequently pulverized. Four techniques are discussed: deposition from aqueous acid solutions (the method in current use by Husqvarna), deposition by fused-salt electrolysis, use of an alkaline solution and iron-ore concentrate, and an amalgam-metallurgical technique.

Most of the methods applicable to production of iron powder may also be used for nickel. It is suggested that the best results are obtained by deposition, from acid-sulphate solutions, of brittle coatings which are then milled to powder. A fine-grained powder can be made by the amalgam-metallurgical method.

The excellent properties of the electrolytic iron powders prompted investigation of the feasibility of producing, by the same method, binary iron alloys containing nickel, manganese, molybdenum or chromium as the second constituent. Attempts made to deposit suitably brittle alloys containing 4–8, 20 and 80 per cent. nickel, using soluble anodes, were successful. A low current density was found to favour deposition of a nickel-rich phase: high current density gave rise to an iron-rich phase. Properties obtained in a sintered nickel-copper steel, using the 4 and 8 per cent. nickel alloys as addition agents, are tabulated. It proved difficult to obtain alloys containing 20–80 per cent. nickel. Production of alloys by fused-salt electrolysis is briefly reviewed: reference is made to the powder characteristics of 18–8 and 3·5–1 chromium-nickel steels obtained in this way.

'The Manufacture and Properties of Metal Powders Produced by the Gaseous Reduction of Aqueous Solutions', pp. 40–52.

The treatment of ores containing nickel, cobalt and copper by gaseous reduction of aqueous solutions is of interest to the powder metallurgist because the refined metals are produced in powder form. The present paper describes the techniques developed by Sherritt Gordon Mines, Ltd., for production of metals by this method, and outlines the properties of the powders obtained.

The processes employed, which use elevated pressures and temperatures to secure increased reaction rates, are essentially hydrometallurgical. The ore is first leached, under oxidizing conditions, in an alkaline or acid medium, to dissolve the valuable metals and permit their separation from silica, iron oxide and other materials which remain in an insoluble residue. After suitable purification to remove iron, arsenic, excess ammonia, etc., the pregnant solutions are adjusted by addition of an acid or base, preparatory to the metal-precipitation stage, in which the reducing gas is introduced. The basic principles of the process are discussed and a résumé is given of the commercial operations involved in production of nickel and cobalt.

The paper ends with sections summarizing properties typical of the nickel, cobalt, nickel/cobalt and copper powders produced.

(The process has also been fully described elsewhere: see, for example, references in *Nickel Bulletin*, 1957, vol. 30, Nos. 4 and 9, pp. 49 and 157; 1958, vol. 31, No. 6, p. 156.)

INFORMAL DISCUSSION ON DEVELOPMENTS IN THE PRACTICE OF COMPACTING AND SINTERING, Mar. 19, 1958; pp. 79–142; Disc., pp. 143–4.

T. W. PENRICE: 'Compacting of Powders using Moulds made from Reversible Gels', pp. 79–84.

With the aim of permitting greater use to be made of isostatic pressing in compacting powders, the author proposes an arrangement by which certain reversible gels are employed as moulds and are subjected to pressure from a plunger in a closed container. The gel exhibits practically the same resistance to compression as a liquid, and exerts uniform pressure on all the faces of the mould cavity containing the powder.

D. K. WORN: 'The Continuous Production of Strip by the Direct-Rolling Process', pp. 85–93.

The continuous production of strip by the direct-rolling process has attracted much attention in recent years. The process involves the rolling of metal powders into a continuous compact which is then sintered, to form strip capable of being processed by conventional cold-rolling and annealing operations. With the advent of relatively cheap metal powders, this process offers promise of eventually proving a competitive alternative to the more usual methods of producing, for example, nickel and copper strip. In the present paper the author reviews the capabilities and limitations of the process, from both the technical and economic points of view.

A description is first given of the plant and technique involved in practical compacting, sintering and subsequent treatment of the strip. Reference is made to a unit producing 12-in. (30-cm.) wide nickel strip from carbonyl powder.

The process has been successfully adapted to the production of strip in, *inter alia*, nickel, copper, iron, steel and brass, but the long sintering times necessary to achieve homogeneity in strip produced from a mixture of elemental powders or, alternatively, use of expensive pre-alloyed powder, render the process less attractive in this respect than ordinary compacting and sintering techniques. Attention is also drawn to the fact that rolling speed during compacting

is limited, owing to risk, above a certain speed, of interference to the powder feed by the escape of entrapped air. A given unit is, moreover, capable of producing strip economically over only a relatively narrow range of thickness. It is emphasized on the other hand that the direct-rolling process lends itself readily to the production, in strip form, of composite materials (for atomic energy and other applications) and to obtaining brittle alloys (e.g., 'Alnico' permanent-magnet alloys) in gauge which could not be achieved by conventional methods.

In two following sections the author outlines the properties required in powders used as the basis materials, and illustrates the properties obtainable in directly-rolled strip by reference to comparative data on nickel strip produced by conventional and by powder-metallurgy techniques. Finally, the relative value of the process is assessed in the light of economic considerations.

J. WILLIAMS: 'The Consolidation of Metal Powders by Hot Working within Sheaths', pp. 94–103.

The author discusses hot-working processes (upsetting, forging, extrusion, rolling, swaging, hydrostatic pressing), selection of sheath materials, and application of sheath-working techniques to consolidation of metal powders.

M. DONOVAN: 'Developments in Vacuum Sintering Furnaces', pp. 104–113.

In recent years powder-metallurgy techniques have been used in the laboratory to produce an increasing number of materials which are highly reactive and cannot be sintered in an atmosphere of either hydrogen or cracked ammonia without formation of deleterious hydrides, nitrides or oxides. The small amounts of aluminium and titanium used to render certain creep-resisting alloys age-hardenable are, for example, readily oxidized, and in an atmosphere of dry hydrogen oxidation will occur due to presence of traces of water vapour, before the sintering temperature is reached. To confer satisfactory protection, inert gases too must be completely free from oxygen. The third alternative, sintering *in vacuo*, which has been widely and effectively adopted, is the subject of the present paper: the advantages derived from such procedure are briefly discussed.

The remainder of the paper is concerned with general discussion of sintering furnaces and the vacuum equipment, heating systems and thermal insulation. In a final section mention is made of the application of graphite-resistor furnaces to sintering of stainless steels and heat-resisting alloys.

O. WINKLER: 'Conditions for Effective Vacuum Sintering and their Realization in Practice', pp. 114–21.

A review of the mechanism of, and optimum conditions for, removal of adsorbed gases from material during vacuum sintering comprises an introduction to a section in which the author suggests means by which practical advantage may be taken of these theoretical considerations. Allusion is made to the problem of incidental evaporation of non-gaseous constituents, and, in emphasizing the difficulty of removing active gases, particularly oxygen, in the absence of a reducing agent, the author urges the efficacy, where appropriate, of sintering initially in a reducing atmosphere and finally *in vacuo*.

J. ANTILL and M. GARDNER: 'Zone Sintering', pp. 133–42.

The problems of distortion and, in the case of chemically reactive materials, of sintering large components in an inert atmosphere at temperatures above 1500°C., are claimed by the authors to be solved by 'zone sintering'. The method, which is analogous to that of zone melting, consists in steadily passing a furnace, at the sintering temperature, over the compacted material. At any given time the hot zone extends over only part of the bar: the scope of the process is therefore considerable, since it is possible, with a small inexpensive furnace, to sinter metal and ceramic tubes and rods with little restriction on their length.

The application of zone sintering to the production of rods and tubes in thorium, uranium and an alumina-base refractory are described.

SYMPOSIUM ON THE POWDER METALLURGY OF CERAMIC-METAL MATERIALS, Dec. 17, 1958; pp. 145–272.

R. KIEFFER and F. BENESOVSKY: 'Recent Developments in the Field of Silicides and Borides of the High-Melting-Point Transition Metals', pp. 145–71.

Attempts to exploit commercially the silicides and borides of the high-melting-point transition metals of Groups IV–VI of the Periodic Table have reached a stage equivalent to that achieved some forty years ago in similar attempts to develop the commercial potential of the hard-metal carbides. The work on carbides met with success only when it was found feasible to minimize the inherent brittleness of the carbides by cementing them with appropriately ductile metals, to produce a satisfactory composite. The possibility of a similar advance in the development of the brittle silicides and borides is considered in this paper.

Discussion of bonding hard-metal silicides and borides is preceded by a review of the present state of knowledge of the relevant systems and of the properties of the resulting compounds. The survey, based on a *bibliography* of 75 items of literature published since 1954, relates to the binary, pseudo-binary and pseudo-ternary silicide systems, the binary, pseudo-binary and higher boride systems, the silicon-boron system, and the transition-metal-silicon-boron systems.

The search for suitable bonding materials is complicated, in the case of the silicides, by the fact that high-temperature applications would necessitate use of a material with a similarly high melting point, and almost all metals likely to be suitable for this purpose form brittle silicide phases. Use of borides for cutting or machining purposes is hampered by

the formation, by the bonding material, of borides and double borides which have poor wettability by liquid phases. Discussion of such problems involved in cementing of silicon and boride materials is included in a review of work by other investigators, which forms an introduction to an account of the authors' own researches in that field. Particular attention is paid to literature referring to the behaviour of borides and silicides in relation to nickel and nickel-containing alloys.

Of the numerous impregnation tests carried out by the authors, only those relating to $MoSi_2$-, WSi_2-, TiB_2-, and ZrB_2-base materials are described. The compounds were compacted into cylindrical specimens and sintered in a hydrogen or argon atmosphere. For the impregnation tests the bonding metal was introduced into a small recess cut in the side of the specimen. The specimen was then heated to the melting point of the bonding material and allowed to cool quickly. Materials found, on the basis of metallographic examination, to have been successfully impregnated were subjected to compression-strength tests.

The bonding characteristics of the following materials are tabulated:

Metals
Silver, platinum, copper, nickel, cobalt, silicon.

Heat- or scale-resistant materials
Nickel-aluminium (70% Ni).
Cobalt-aluminium (70% Co).
'Hastelloy' (60-20-20 Ni-Mo-Fe alloy).
'Thermenol' (79-16-5 Fe-Al-Mo alloy).
18-8 chromium-nickel stainless steel.

Silicon alloys
Ferro-silicon (50% Si).
Nickel-silicon (30% Si).
Aluminium-silicon (10% Si).

Boron-containing alloys
Ferro-boron (16% B).
Nickel-boron (14% B).
Chromium boride (20% B).
'Colmonoy 6' (Ni-base Cr-Si-B alloy).

Most of the pure metals were found to have reacted with the silicides. Compression strength increased as a result of impregnation, but the specimens were still very brittle. Micrographs of nickel composites revealed considerable dissolution of the skeleton, with formation of one or two new phases; the specimens were brittle. Similar results were obtained with the cobalt-impregnated composites. The $MoSi_2$ and WSi_2 specimens were satisfactorily impregnated with silicon, and the ferro-silicon, nickel-silicon and aluminium-silicon alloys, but again considerable dissolution of the skeleton occurred, accompanied by brittleness.

The boron alloys impregnated the silicides well, though, in some cases, as with the high-temperature and scale-resistant alloys, extensive dissolution took place. The two disilicides stood up well to impregnation with platinum, though not without a great deal of erosion, which, it is suggested, might be inhibited by first alloying the platinum with silicon. Silver was not found suitable as a bonding agent, on account of its poor wettability, but the results achieved with a palladium-silver alloy were promising.

In general, impregnation of TiB_2 and ZrB_2 with the same metals and alloys as were used for the silicides produced better results, since, in many cases, the reactions did not cause such extensive erosion. TiB_2, for example, reacted with nickel to form a eutectic composite. Both borides were satisfactorily impregnated with silicon and silicon-iron alloys, though, as with the boron alloys, dissolution was considerable.

Sintered compacts impregnated with the heat- and corrosion-resisting alloys also showed properties which would render such materials suitable for some purposes: for example, compacts bonded with the 18-8 stainless steel exhibited relatively high compression strengths. Platinum was suitable for impregnation purposes, and, though silver was not absorbed, a palladium-silver mixture proved satisfactory.

D. A. ROBINS: 'Bonding in Carbides, Silicides and Borides', pp. 172–88.

The hypothesis that many of the properties of the transition metals, their alloys and their compounds can be understood in terms of a relationship between the co-ordination of the metal atoms and the number of bonding electrons per atom is applied to the carbides, silicides and borides of the transition metals of Groups IVA, VA and VIA.

E. GLENNY and T. A. TAYLOR: 'The High-Temperature Properties of Ceramics and Cermets', pp. 189–226.

Development of aircraft gas-turbine engines with improved thrust and higher power outputs, involving higher service temperatures, has aroused interest in the possibility of using ceramic materials or cermets for components which will be called upon to operate at temperatures above those for which metallic materials are serviceable. Cermets in particular have been the subject of considerable research in the U.S.A.

The present paper reports tests carried out at the National Gas Turbine Establishment, Farnborough, to determine the relevant properties, at temperatures up to 1200°C., of ceramics and cermets potentially useful for turbine blading.

The materials selected for study are indicated below.

Oxides: Fused silica, sintered alumina.

Oxide/Metal Cermets: Eight compositions, based on the chromium-alumina and chromium-alumina-molybdenum systems. The metal or alloy content ranged from 20 to 80 per cent.

Carbides: Three commercial grades of silicon carbide.

Nitrides and Silicides: Two experimental grades of silicon nitride; molybdenum disilicide.

Carbide/Metal Cermets: Development of cermets for high-temperature applications has been largely confined to metal-bonded titanium carbide. Four

commercial types, of the following composition, were evaluated:

'40N' (TiC 54, Ni 40, Cr_3C_2 6, per cent.)

'CM1' (TiC 65, NbC 11, Fe 11, Cr 5·7, Ni 5·6, TaC 0·7, per cent.)

'K163B' (TiC 57, Ni 30, Mo 5, solid solution of carbides of Nb+Ta+Ti 8, per cent.)

'K183A' (Composition not stated)

Heat-Resisting Alloys: Comparative tests were made on the following nickel-base alloys: the wrought age-hardenable alloys 'Nimonic' 90, 95 and 100; the casting alloys 'Nimocast 258' and 'G.64'. The values obtained served as criteria against which the merits of the other materials could be realistically assessed.

All the materials were evaluated by a comprehensive series of tests in which the following properties were determined: bend strength and bend creep-resistance, tensile-creep and stress-to-rupture properties, fatigue-resistance, resistance to thermal shock and thermal fatigue, oxidation-resistance, and resistance to mechanical shock. For some of the tests established methods were employed, but for others (e.g., those for determination of tensile creep-strength and thermal-shock resistance) new techniques were developed.

It is concluded from the data obtained that it is possible to produce ceramics and cermets which will exhibit satisfactory creep-, fatigue- and oxidation-resistance at temperatures higher than those at which heat-resisting alloys are currently used. The more promising of the materials tested, have, however, a comparatively low level of resistance to thermal and mechanical shock. With the exception of fused silica, it is evident that under conditions simulating gas-turbine service the resistance of all the brittle materials to thermal shock and thermal fatigue is considerably inferior to that of 'Nimonic 90'. Highest impact strengths were obtained with the metal-bonded carbides, but these were only about 10 per cent. of that of the casting alloy 'Nimocast 258'. The creep strength of an American self-bonded carbide was outstanding. Of the two experimental silicon-nitride compositions, the low-density grade exhibited good resistance to thermal shock but had only a slight advantage in strength at 1000°C. *vis-à-vis* 'Nimonic 90', while the good creep strength of the high-density grade was counterbalanced by its only moderate resistance to thermal shock. The most creep-resistant of the ceramics or cermets (*viz.*, the self-bonded silicon carbides and the 20 per cent. Cr/Al_2O_3 cermet) and those most resistant to thermal shock (fused silica and silicon nitride) have the serious disadvantage of very low resistance to mechanical shock. In general, the strongest of the metal-bonded carbides revealed a better combination of the required properties than the other ceramics and cermets. It is emphasized that for rotor blading the relative suitability of various materials should be assessed on a strength-to-weight basis, and by this criterion the low strengths obtained for such low-density materials as silicon nitride are somewhat misleading.

The authors' final assessment of the results is that 'at the present stage of development it seems that none of the materials under review has a sufficiently good combination of the properties essential for satisfactory service in an aircraft gas turbine. The likelihood of their application has been reduced by recent advances in creep-resistant wrought and cast alloys.'

(*End of Symposia*)

Bonding of Cermets to Metals

G. R. VAN HOUTEN: 'Transition Layer is the Key to Good Ceramic-to-Metal Bonds.'
Materials in Design Engineering, 1958, vol. 48, Dec., pp. 112-14.

A major problem in joining metals to ceramics is the difficulty of wetting the surface of the ceramic by the bonding metal. Bonding is therefore usually accomplished by means of a thin coating of a material which will adhere to the ceramic and form a transition layer capable of being wetted by the bonding metal.

This article describes four processes which have been proposed for production of ceramic-to-metal bonds and summarizes their advantages and limitations. The first involves the use of silver-glass frit: simple in application, but unsuitable for high-temperature use. The other three (the molybdenum-manganese, metal-hydride and active-metal techniques) can be used to produce sound ceramic-to-ceramic or ceramic-to-metal seals which will withstand exposure to temperatures of the order of 1100°F. (595°C.) or even higher.

The article forms an interesting supplement to the author's comprehensive review of ceramic/metal bonding to which reference was made in *Nickel Bulletin*, 1959, vol. 32, No. 2, p. 38.

Influence of Temperature on the Bursting Pressures of Nickel, 'Monel' and Stainless-Steel Bursting Discs

The effective functioning of bursting discs used as safety devices in plant operating under pressure is contingent on their bursting at a specified pressure below the danger limit but operating reliably for long periods without bursting at lower pressures. The problem has been satisfactorily solved for plant operating at ambient temperature, but the more complex problem of adapting discs to use under elevated- and sub-zero-temperature conditions is still the subject of research. Since the bursting pressure of a disc may vary appreciably with temperature, the degree of protection afforded may be governed by the temperature at which the plant operates: at elevated temperatures the influence of creep must also be taken into account. Accumulation of data which will permit reasonably accurate prediction of the effective service life of a disc, under a wide range of temperature and other operating conditions, has recently become a matter of importance, and in this connexion the work described in the three papers abstracted overleaf contributes to the information available.

H. R. WRIGHT: 'The Effect of Temperature on Bursting Discs.'

Trans. Instn. Chemical Engineers, 1958, vol. 36, pp. 69–78.

Tests were carried out, at temperatures ranging from −80°C. to +400°C., on discs of the plain diaphragm type (thicknesses are given) made from aluminium, copper, silver, platinum, nickel, 'Monel', palladium, mild steel, and titanium-stabilized 18–8-type chromium-nickel steel. (None of the materials, was, however, tested over the entire temperature range.) The discs were brought to temperature, and tested to bursting point, by immersion in boiling water; by exposure to steam, liquid and solid carbon dioxide, melting ice, etc.; or by being heated under pressure in an electric furnace. Full particulars are given of procedure and apparatus used.

Tabular and graphical data show the observations made with regard to the influence of temperature on the bursting pressures of discs of each material tested. With the exception of mild steel, bursting pressures fell with rise in temperature; for example, by 10–50 per cent. over the range room temperature to 250°C. The bursting pressure of 'Monel' was the least affected. The strength of mild-steel discs, although falling off initially, recovered at about 200°C., but owing to its poor corrosion-resistance mild steel is rarely used for this purpose. 'Monel' is therefore considered the most suitable material for discs which are required to operate at elevated temperatures, particularly since it exhibits excellent resistance to corrosion by a wide range of fluids. This material is, however, subject to certain limitations, in that its high strength prevents its use for small-diameter discs with low bursting pressures: an effective diameter of approximately 6 in. (15 cm.) would be necessary to obtain a bursting pressure as low as 100 p.s.i. (0·07 kg./mm.^{2}).

Details are given of experiments with aluminium discs, in which deformation was measured as a function of progressively increased pressures, and on the basis of the data so obtained the author outlines the manner in which metal diaphragms function as bursting discs. Investigation was also made of the relationship between the ductility of disc material at normal and at elevated temperatures and the bursting pressure of the disc.

Creep was found seriously to lower the bursting pressures of some of the materials tested. The life of a disc will be short unless the ratio of the operating pressure to short-time bursting pressure at service temperature is limited to a safe value: recommended values (at 20° and 175°C.) are listed for aluminium, silver, copper, nickel (0·95 and 0·9, respectively) and stainless steel (0·95 and 0·9, respectively).

T. B. PHILIP: 'The Effect of Temperature on Bursting Discs.'

Ibid., pp. 79–80.

Data are presented for discs of aluminium, silver, nickel, 'Monel' and 18–8-type stainless steel, tested over the temperature range 15°–300°C., and brought from atmospheric to bursting pressure in approximately one minute.

A number of inflexions were noted in the curves obtained: these are attributed to change in properties of the materials, and the curves are regarded as reasonable guides to basic bursting pressures under controlled conditions. In practice, however, the margin needed between working pressure and bursting pressure is much greater at higher temperatures than at low levels.

J. F. W. BROWN: 'The Effect of Operating Temperatures on the Bursting Pressure of Some Materials Commonly used for Bursting Discs.'

Ibid., pp. 81–6.

The paper is presented in three parts. In the first, the author gives details of apparatus designed to determine bursting pressures at sub-zero and at elevated temperatures, and permitting pressure to be increased from atmospheric to bursting within 10–15 seconds. In the second section, data obtained from determination of sub-zero bursting pressures for nickel, silver, aluminium and copper specimens are presented, and are correlated with data derived from tests in the range 30°–450°C. In the last section these data are discussed in connexion with design of discs intended for service at elevated and sub-zero temperatures.

Maximum working temperatures are suggested for bursting discs of gold, aluminium, copper, nickel (400°C.), palladium alloy, platinum alloy and silver. The excellent creep-resistance of nickel up to 400°C. (a sufficiently high temperature for most applications involving bursting discs) makes it one of the most suitable of the materials considered for use at elevated temperatures. The principal limiting factor is the readiness with which the metal is attacked by certain corrosives, but use of composite discs having one or both faces protected by a thin disc of silver, gold, platinum or even aluminium could offset this disadvantage. The protective face would have little or no effect on the ultimate bursting pressure, and the main strength at elevated temperatures would be provided by the nickel.

At sub-zero, as at elevated temperatures, particular attention must be paid to the effect of thermal conditions, on the apparatus as a whole. Whereas the bursting pressure of the disc is more affected by the higher temperature than is the strength of the apparatus being protected, it is considered possible that at sub-zero temperatures, and with bursting discs made from certain materials, the increase in the rupture pressure of a disc could be greater than the increase in strength of the vessel it is protecting. For this reason the sub-zero properties of nickel make it one of the most suitable materials for such applications. Graphical data on the bursting pressures, at sub-zero temperatures, of aluminium, nickel and copper are compared with curves showing variation in the tensile stress of the three metals with lowering

of temperature within the same range. A marked parallel is evident between increase in tensile strength and increase in bursting pressure.

A brief account is given of preliminary investigation on the influence of creep on bursting pressures of silver and nickel discs. For nickel a life of 2,000 hours at approximately 93 per cent. loading is mentioned.

Discussion arising from the three papers is recorded on pp. 86–90.

Bright-Annealing Furnaces and Ancillary Equipment

A. E. PICKLES: 'Bright Annealing.'

Metal Treatment, 1958, vol. 26, Jan., pp. 7–14.

After brief introductory notes on the advantages of annealing in protective atmospheres, the author describes the principal types of bright-annealing furnaces available and reviews the atmospheres used in them. The compositions of the special atmospheres are discussed, with information on the sources from which they are obtained: brief consideration is given also to methods used for removal, from the protective gases, of constituents which might prove deleterious to the materials being heat-treated. Requirements concerning type of furnace and atmosphere are tabulated in relation to the bright-annealing of various types of copper, cupro-nickel, brass, nickel silver, stainless steel, carbon steel and mild steel.

Inert-Gas Consumable-Electrode Welding of Steels in Thin Section

T. McELRATH: 'Inert-Gas Consumable-Electrode Welding of Thin Material.'

Welding Jnl., 1959, vol. 38, Jan., pp. 28–33.

Although covered-electrode and tungsten-arc welding methods have for some time past been successfully used at low welding speeds on material of 16 gauge and above, difficulties have been encountered in using these processes on thinner material or at higher welding speeds. The inert-gas consumable-electrode process, which is successfully employed for welding the common metals in $\frac{1}{8}$-in. (3-mm.) or thicker gauge, has not proved satisfactory for joining these materials at high production speeds. This paper is introduced by a discussion of the limitations of existing methods as applied to thin materials, and describes new developments in inert-gas consumable-electrode welding procedure by which such limitations have been overcome.

The modified method incorporates a combination of short-arc techniques, suitable constant-potential power-supply units, and the use of feed wire of small diameter. It is stated that by the use of this process it is possible to achieve high production welding speeds on aluminium, stainless steel and carbon steel, on material ranging from 0·015 to $\frac{1}{8}$-in. (0·375 to 3-mm.) in thickness. Operation can be manual or automatic.

NICKEL

Passivity in Metals: International Colloquium

See abstract on p. 89.

Resistance of Nickel to Hydrochloric Acid, Hydrogen Chloride and Chlorine

See abstract on p. 89.

Influence of Temperature on the Properties of Nickel Bursting Discs

See abstracts on p. 69.

Recovery Treatment for Graphitically Embrittled Nickel

'Recovery of Graphitically Embrittled Nickel.'

Corrosion, 1959, vol. 15, Jan., p. 112.

This brief extract of a recent paper by W. SZYMANSKI refers to failure, by embrittlement, of nickel in a shell-and-tube-type heat exchanger used in a high-temperature process. Analysis of the failed material showed the presence of 0·10 per cent. total carbon, 0·06 per cent. graphitic carbon and 0·006 per cent. sulphur. Coke had accumulated on the interior surface of the tubes, but there was no evidence of sulphur attack. (The condition of the material is illustrated.)

It is pointed out that intergranular graphitic embrittlement of nickel can occur at about 455°C. when carbon exceeds 0·03 per cent. and that in this case graphite, occurring at the grain boundaries, had had a pronounced detrimental effect on the ductility of the tubes, resulting in subsequent cracking under the influence of operating stresses. Because service conditions give rise to coking, use of a specially low-carbon grade of nickel would not solve the problem, since, in operation, the material would ultimately absorb sufficient carbon to cause embrittlement. In the case under consideration, replacement of nickel by 'Inconel' (nickel-chromium-iron alloy) has resulted in trouble-free service.

Because the nickel tubes were, apart from their brittleness, in good condition, experiments were carried out to ascertain the possibility of restoring them by thermal treatment. Heating at 1800°F. (980°C.) for 15, 30 or 60 minutes, followed by quenching, showed that a 60-minute treatment at that temperature, followed by quenching in a water-alcohol solution, gave almost complete recovery of the embrittled material, without impairing corrosion-resistance, as assessed by tests in 30 per cent. sodium hydroxide at 120°C. or 9 per cent. hydrochloric acid at 105°C. It is suggested that nickel so 'restored' would be usable in applications which do not involve embrittling conditions.

Determination of Nickel in Cast Iron by Absorptiometric Methods

W. E. CLARKE: 'Comparative Tests on some Instruments used in Absorptiometric Methods of Analysis.'
Brit. Cast Iron Research Assocn., Jnl. Research and Development, 1958, vol. 7, Dec., pp. 360–91;
Research Report 496.

The report presents the results of a study of the relative performance of the Hilger 'Uvispek' spectrophotometer, the 'EEL' absorptiometer and the Hilger 'Spekker' absorptiometer, when used for routine analysis of cast iron. In particular, the author records and discusses the findings of experiments designed (1) to establish optimum conditions for each type of instrument in relation to specific determinations, and, where necessary, to plot absorption spectra under such conditions; (2) to compare prism- and filter-type instruments; (3) to compare single and double photo-cell absorptiometers; (4) to compare the performance of tungsten-filament and mercury-vapour lamps.

Conditions are recommended for determination of the following materials in cast iron: manganese, nickel, copper, molybdenum, chromium, titanium and vanadium, cerium, bismuth, cobalt and silicon.

Direct Rolling of Strip from Nickel Powder

J. A. LUND: 'Roll-Compacting Produces Pure Nickel Strip.'
Jnl. of Metals, 1958, vol. 10, Nov., pp. 731–4.

The possibility of producing metal strip by continuous compacting of powders has for many years been a subject of considerable interest and relevant patents date back to 1902, but the first reported experimental work on direct rolling of metal powders into continuous dense strip was that of NAESER and ZIRM in 1950 (*Stahl und Eisen*, vol. 70, pp. 995–1003). Their paper described roll-compacting of iron powder, sintering, and re-rolling the sintered compact to develop full density. It was claimed that the final product so obtained showed mechanical properties at least as good as those of strip of the same composition which had been rolled from ingot.

Since that time work on exploitation of the commercial possibilities of the technique has continued (see, for example, the paper by WORN on direct rolling of strip to which reference is made on p. 66 of this issue). The present paper records the results of a study of the processing variables involved in application of the NAESER and ZIRM technique to direct rolling of strip from nickel powders produced by the Sherritt Gordon hydrogen-precipitation process (see abstract on p. 66).

Three grades of pure nickel powder, having different particle-size distribution, were used for the experiments. The variables examined, the scope of the experiments, and the main conclusions reached are outlined below.

Density

Determination of density of green strip (sintered for 5 minutes at 2250°F. (1230°C.)), was made as a function of roll gap, rolling speed and grade of powder. It was found that high density was favoured by use of small roll gaps and powders of fine particle size. For two grades of the powders studied, increase in rolling speed gave strip of lower density for all the roll gaps used: the effect of rolling speed on the third grade of powder varied. Density variations across the width and along the length of the strip ranged within $\pm$ 3 per cent. of the average value.

Roll Pressure

The compacting pressure of the rolls, for a given roll gap, roll speed and grade of powder, was estimated by comparing the density of the green strip with that of thin compacts pressed statically, at known pressures, from the same powders.

Densification of Sintered Strip

Green strip sintered for 15 minutes at 2250°F. (1230°C.) was cold re-rolled four times, using single passes and an annealing treatment of 25 minutes at 1600°F. (870°C.) after each pass. A roll speed of 35 ft./min. (10·5 m./min.) was used throughout this phase of the investigation, and the roll gaps for the first, second, third and fourth passes were, respectively, 0·015, 0·010, 0·005 in. (0·0375, 0·025, 0·0125 mm.) and zero. It was therefore possible to measure density of the strip at each stage in the densification process. Data tabulated show a wide scatter after the first cold re-rolling, although, in general, the relative density of the materials after compacting and sintering was maintained after the first cold reduction. After the fourth pass density values showed a wide scatter and, whereas annealing after the second and third reductions resulted in significant increase in density, the reverse was invariably the case after the fourth cold reduction.

Maximum tensile strength and elongation values for the rolled strip compared favourably with those of cast and wrought nickel in comparable condition. Ultimate tensile strength and elongation rose significantly between the third and fourth stages of the densification cycle, and decrease in density which followed the fourth cold reduction and annealing was not accompanied by fall of mechanical properties.

From the results of the investigation the author concludes that the green density of roll-compacted nickel strip appears to have very little influence on the properties which can be finally obtained after sintering and densifying by a given amount of cold re-rolling. This finding indicates that, in terms of the quality of the final product, particle size, roll gap and roll speed are relatively unimportant variables. In a commercial application of this process, however, the physical characteristics of the green strip would be important, since the strip would have to be coiled or otherwise handled. The green strip of highest density was found to be the strongest, but it was also the least flexible: it is believed that optimum handling characteristics would be exhibited by green strip of intermediate density. It is suggested

that not more than two reductions, of 20–30 per cent. each, would be required to obtain optimum properties in strip produced by the direct-rolling technique employed.

In other experiments carried out to determine the efficacy of using sintering temperatures below 2250°F. (1230°C.) the compacted strip was sintered at the following temperatures and for the times shown, cold-rolled to achieve a 30 per cent. reduction, and finally annealed for 20 minutes at 1600°F. (870°C.).

Temperature		*Times*
°F.	°C.	Minutes
2250	1230	15
2000	1093	15, 30 and 60
1900	1035	15, 30, 60 and 120

Tensile strength and elongation values of the strip were correlated with the sintering treatment. The following conclusions are drawn:

(*a*) The properties of strip cold-rolled after sintering for 15 minutes at 1900°F. and 2000°F. (1035°C. and 1093°C.) were almost comparable to those of strip sintered for the same time at 2250°F. (1230°C.).

(*b*) Tensile strengths of 46,000–48,000 p.s.i. (20·5–21·5 t.s.i.; 32·5–34 kg./mm.^{2}) could be developed after only 30 per cent. reduction in strip sintered for 30 minutes or longer at 1900° and 2000°F. (1035° and 1230°C.). Longer sintering at these temperatures did not result in any appreciable improvement in properties obtained after cold-rolling and annealing.

(*c*) Per cent. elongation of strip which had been cold-worked 30 per cent. after sintering for 30 minutes or more at 1900° and 2000°F. (1035° and 1230°C.) was superior to that of strip which had been similarly worked after sintering for 15 minutes at 2250°F. (1230°C.).

It is concluded that two processes are involved in the sintering operation: densification, due to sealing of the voids between powder particles, and grain growth. Both processes are favoured by high temperatures and long times of sintering, but large grain size has a deleterious effect on properties when the residual porosity after sintering is chiefly concentrated at the grain boundaries.

The paper is well illustrated by photomicrographs showing the structure of powders after various treatments.

Symposia on Production of Metal Powders, Compacting and Sintering, Cermets

See abstract on p. 65.

Structure of Ground Nickel Powder

A. KOCHANOVSKA: 'An X-Ray Study of the Fine Structure of Ground Powdered Nickel.'

Czechoslovak Jnl. of Physics, 1957, vol. 7, pp. 455–67.

The author discusses the effects produced in an aggregate of metal crystals by plastic deformation, and outlines the manner in which such effects are manifested in X-ray measurements, i.e., changes in the widths, intensities and positions of diffraction lines, and in interplanar distances. In this connexion an X-ray study was made of structural changes in nickel powder subjected to grinding for 8, 16, 24, 48, 72 or 96 hours. The main findings of the investigation are outlined in *Metal Powder Report*, 1958, vol. 13, Nov., pp. 66–7.

ELECTRODEPOSITION AND OTHER COATING METHODS

Nickel Salts for Plating: German Standard Specification

DEUTSCHER NORMENAUSSCHUSS: 'Electrodeposited Coatings: Nickel Salts for Nickel-Plating Solutions.' *D.I.N.* 50 970, issued Oct. 1958; 2 pp.

The tentative form of this revised specification, as issued for comment before standardization, was abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 1, p. 3. The major change in the final form, now published, is the introduction of a high-purity grade of nickel chloride. The specification also stipulates acceptance tests defining the quality of the salts in terms of the deposits obtained from solutions in which such salts are used.

The main provisions of the standard are summarized in the table below and that on p. 74.

Nickel and Cobalt Content of the Salts

Salt	Ni + Co % min.
Nickel sulphate, high-duty and standard grades	20·5
Nickel chloride, high-duty and standard grades	23·7

Brightening Agents in Nickel Plating

E. B. SAUBESTRE: 'The Chemistry of Bright Nickel Plating.'

Plating, 1958, vol. 45, Dec., pp. 1219–27.

As economical alternatives to buffing of matt deposits electrodeposition from an organic bright-nickel or from a levelling solution is the means most commonly employed in commercial practice. The brighteners used and the chemistry of their brightening activity form the subject matter of the present paper.

Brighteners

Proprietary bright-nickel solutions of these types are based on the same constituents as those used in

Purity Requirements for Nickel Salts

D.I.N. Specification 50 970

Salt	Permissible Impurities							Residue insoluble in N/10 Sulphuric Acid
	Co %	Zn %	Fe %	Cu %	Pb %	Cd %	As** %	
Nickel Sulphate High-duty grade	0·5	0·010*	0·005	0·002	0·002	0·005	0·001	0·05
Nickel Sulphate Standard grade	0·5	0·01	0·03	0·01	0·02	Not specified	0·001	0·2
Nickel Chloride High-duty grade	0·5	0·010*	0·010	0·002	0·002	0·005	0·001	0·5
Nickel Chloride Standard grade	0·5	0·01	0·05	0·01	0·01	Not specified	0·001	0·2

* Preferably 0·005 per cent. max.

** As free as possible from arsenic.

the Watts bath (the nature and effect of which were discussed in a previous paper: see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 12, p. 317), but the constituents are used in different concentrations and with the addition of organic brighteners. These brightening media are of two distinct types: those of the first class have two functions:—although not themselves conferring lustre, they make possible deposition of bright coatings over a bright substrate, and also permit the second class of brighteners to be present in an acceptably wide range of concentrations. Brighteners of the second class, which produce mirror-like lustre in the coatings, are therefore complementary to those of the first type, without which brighteners of the second class would give rise to excessive brittleness in the nickel deposits. An outline is given of the types of organic material falling into the respective classes, and additives representative of both types are listed.

Co-deposition of the brightener, which is an important factor in bright nickel plating, may involve either its permanent deposition by cathodic reduction or its adsorption on the cathode surface. The cathode reactions involved are discussed in relation to hydrogenation and dehalogenation and to reduction of nitrogen compounds, oxygen compounds, and additives of $=C-SO_2-$ type. This information is supplemented by a table illustrating cathodic reductions: reagents and the corresponding reduction products are listed. Another table gives a review of typical anodic reactions, relating to oxidation of sulphur-, nitrogen-, oxygen-containing and aromatic compounds, and to halogenation.

The effect of organic brighteners has until now been considered mainly in terms of adsorption and desorption of the addition agent; less attention has been paid to compound- or complex-formation between ions and the brightener. Organic nickel compounds may be classified into three types: organo-metallic compounds, esters, and organic co-ordination compounds. The first two types are relatively unimportant, but nickel co-ordination complexes can significantly influence the conditions of deposition. In this connexion, the author discusses the formation of co-ordination compounds with nitrogen, sulphur, oxygen and arsenic, and indicates the implications involved in the use, as brighteners, of compounds containing these elements. Reference is made also to the influence which brighteners may exert on the acidity of boric acid in the cathode film.

In the last two sections of his review, the author recapitulates the factors which must be taken into account in development of suitable brighteners, and briefly summarizes the salient findings with respect to the relationship between the properties of the deposits and the brighteners and operating conditions used in producing them.

The review is supported by a *bibliography* of 40 items.

Levelling

Bright-nickel-plating solutions of the types discussed by the author usually yield deposits which do not level sufficiently to cover polishing scratches on the basis metal. Interest has therefore developed in modifications which would improve levelling characteristics and produce ductile, mirror-bright deposits. The earliest approach to this problem was deposition of a ductile, almost bright nickel which could readily be buffed to the desired finish: coumarin-containing solutions are typical of the electrolytes used for that purpose. More recently, interest has centred on direct adaptation of organic bright-nickel baths to produce levelling: the solutions

mainly used (in addition to the coumarin-containing electrolytes) are: (1) acetylenic alcohols, and (2) nitrogen-containing ring compounds such as pyridines and quinolines, and quaternary compounds such as pyridinium and quinolinium compounds. Such baths are often characterized by poor throwing power, and in this respect baths containing coumarin, although not so efficient in levelling, have superior properties. The author expresses the opinion that within the next few years all organic bright-nickel baths will be of the levelling type.

Rapid Determination of Additives in Bright-Nickel-Plating Solutions

K. SZMIDT, T. ZAK and Z. KWIATKOWSKI: 'Rapid Quantitative Methods for the Determination of Brighteners, Levellers and Anti-Pitting Agents in Nickel Electroplating Baths.'

Trans. Inst. Metal Finishing, 1958, vol. 36, Autumn, pp. 17–21.

Accurate control of bright-nickel-plating solutions has been hindered in the past by lack of rapid quantitative methods for determination of addition agents. The low concentrations and wide variety of these agents and the difficulty (especially in the case of organic compounds) of separating them, are factors which have militated against easy solution of the problem. This paper gives details of results obtained by experimental application of a technique based on polarographic and surface-tension measurements. The theoretical principles underlying the technique are discussed and the procedures used are exemplified by descriptions of methods employed to determine *p*-toluenesulphonamide in the absence of wetting agents, wetting agents (sulphonated isopropylnaphthalene) in the absence of *p*-toluenesulphonamide, and *p*-toluenesulphonamide and wetting agents in solutions containing both additives. The technique may also be adapted to determination of metal-ion additions, and its application to estimation of cadmium concentration is outlined. The polarographic method is effective in determination of brighteners and wetting agents only when no other organic or colloidal impurities are present.

To gain practical confirmation of the validity of the technique recommended, additions were made to plating solutions on the basis of the results obtained. Satisfactory nickel coatings were produced.

Electrodeposition of Nickel from Sulphate-Oxalate Solution

A. J. STEIGER: 'Hard Nickel Plating in Russia.'

Metal Finishing, 1959, vol. 57, Jan., pp. 52–3.

The process described in this article (which is based on a recent report by E. F. LYAKOVICH) was developed to meet the need for very hard, wear-resistant coatings for instrument parts and other applications in which such properties are essential.

The composition of electrolyte recommended as optimum is shown in the right-hand column.

	g./L.
Nickel sulphate	140
Ammonium oxalate	300
pH	7·5–8 (quinhydrone electrode)
Current density	10 amp./dm.^{2}
Temperature	75°–80°C.

It is claimed that operation under the above conditions gives a rate of deposition of 50–60 microns (0·002 in.–0·0024 in.) per hour, i.e., a rate 5–6 times faster than that normal with sulphate electrolytes. It is stated that the coatings produced are characterized by very high hardness, which can be further raised by heat-treatment; maximum hardening appears to be achieved by an hour's treatment at about 300°C. The deposits are smooth and bright. Corrosion-resistance of the as-deposited coatings is believed to be inferior to that of nickel deposits made from sulphate baths, but this property is improved by heat-treatment. The heat-treated coating assumes a 'golden tinge'.

This article includes discussion (based on the origina Russian report) of the influence of composition of the electrolyte, pH and current density. The throwing power of the sulphate-oxalate solution is also considered.

Structure of Electrodeposited Nickel

B. C. BANERJEE and A. GOSWAMI: 'The Structure of Electrodeposited Nickel.'

Jnl. Electrochemical Soc., 1959, vol. 106, Jan., pp. 20–3.

Previous work on the crystal structure and orientations of nickel electrodeposits had shown them to be greatly influenced by variation in plating conditions (see, for example, papers by the same authors to which reference was made in *Nickel Bulletin*, 1957, vol. 30, No. 12, p. 217).

The present report gives an account of a comparative study, by electron diffraction, of the crystal structure and orientations of nickel coatings deposited, under various operating conditions, from nickel-sulphate and sulphate/chloride solutions commonly used in industrial plating. In particular, the investigation involved determination of the influence, on structure, of the following variables: pH, temperature, current density, addition of oxidizing agents, metal-ion and chloride-ion concentrations, and mechanical stirring.

Various preferred orientations, mixed or otherwise, were observed, depending on the plating conditions used. Factors contributing to the orientations exhibited are discussed and the findings are correlated with the mode of growth of the deposit.

Influence of Geometry of the Basis Metal on the Distribution of Nickel Electrodeposits

E. RAUB: 'Investigation of the Distribution of Electrodeposited Metals.'

Metalloberfläche, 1958, vol. 12, Dec., pp. 353–60.

The throwing power of a plating solution is the

main factor which determines the relative thickness to which the coating is electrodeposited at various points on the basis metal. Throwing power is, however, itself influenced by numerous other variables, for example: the primary current distribution on the surface of the workpiece (which is in turn governed by the shape of the component, the arrangement of the bath, the shape of the anode and its distance from the component); the secondary current distribution; the current density; and the conductivity of the solution. The combined effect of all these factors is impossible to forecast: methods so far developed to determine throwing power provide only a means of comparing the properties of different solutions under similar experimental conditions. The corrosion-resistance of an electrodeposit is governed by the lower limit of the thickness range in which the metal is deposited over the surface, and is, to this extent, directly related to the throwing power of the solution. Since the geometry of the component is of great importance in this respect, the investigation described was carried out to determine its influence on distribution of copper and nickel electrodeposits.

Specimens for plating were of simple geometrical shape with a hollow cylindrical body and a semi-spherical closed end, with an annular flange at the open end. This basic shape was modified in the eight specimens used in the investigation, so as to provide a means of assessing the influence of variation in the width of the flange and the diameter and length of the specimens. Details of the dimensions used are given. Variation in the thickness of the deposits was determined by microscopical measurements on cross-sections cut lengthwise along the plated specimens (the underside of which had, prior to plating, been lacquered as a stop-off).

The nickel coatings were deposited either from a Watts bath or from a bright-plating solution of high levelling power. For copper plating a cyanide solution was used. In some of the experiments the solutions were agitated.

In one phase of the programme the specimens were coated directly with nickel to an average thickness of 20 or 40μ: in others a coating of copper 30- or 10-μ thick was deposited prior to plating with, respectively, 10 or 20μ of nickel. The measurements made are summarized in the form of curves in which the thickness of the deposit is plotted (as a percentage of the average thickness) against the specific location of the deposit in a cross-section extending lengthwise from the outside edge of the flange to the mid-point of the semi-spherical bottom.

Consideration of the data leads the author to conclusions which may be summarized as follows:

Both in the Watts nickel solution and in the commercial bright-nickel-plating electrolyte the lines of current were found to be highly concentrated at the external edge of the flange. The sharp inner edge of the flange was therefore able to influence the thickness curves only when the width of the flange was at or above a certain limit (12 mm. in the experiments described). If the width of the flange was too narrow, the influence of the inner edge, on the distribution of the nickel, was insignificant. The thickness of the nickel deposit decreased steadily from the outer to the inner edge of the flange. With increase in the depth of the specimens, deposit thickness fell rapidly to a relatively small value. The thickness curves were, however, unaffected by variation in the diameter of the specimens.

The results derived from the copper-plated specimens differed greatly from the above findings. The concentration of the lines of current at the sharp narrow edge of the flange was very much less pronounced and the effects of the inner edge on the thickness curve of the copper deposit were evident (in a more or less sharp increase to a maximum level) even when the flange itself was relatively narrow. The throwing power of the copper solution, however, decreased sharply when use was made of a 3-mm. diameter specimen, until there was no difference between the throwing power of the weakly acidic nickel solutions and that of the cyanide-copper electrolyte. Agitation during the copper plating resulted, in the case of specimens with the narrowest openings, in a reversal of the results usually obtained, in that the copper was deposited to a narrower range of thickness than in the static solutions.

The practical significance of these findings is also summarized. If the component to be plated is of sharply defined geometry, electrodeposition of copper from a cyanide bath will result in a much more uniform coating than would deposition of nickel, provided that the current flow is not concentrated in indentations. In the case of components of more restricted geometry, impairment of the current flow will deleteriously affect the throwing power of the cyanide-copper solution and it might, under certain conditions, be even worse than that of the nickel solution. In contrast to the normal rule, throwing power of the copper solution can, in many cases, be improved by violent agitation of the electrolyte, which would tend to induce a certain flow of current within the identations.

On the basis of the results obtained, it is concluded that openings of less than 6-mm. diameter and similar depth can produce a lack of convective flow which can have an adverse effect on the throwing power of the cyanide-copper solution. Even if agitated, however, the copper solution has no advantages *vis-à-vis* the nickel electrolyte when the depth of the 3-mm. diameter opening is 6 mm. or more. An improvement in the distribution of the electrodeposit over the entire surface of the component does not therefore always follow from partial substitution of the nickel deposit by a preliminary copper coating.

Resistance of Electrodeposited Nickel to Attack by Detergents

See abstract on p. 94.

Effect of Purity of Nickel-Plating Solutions on Coverage by Chromium

R. H. ROUSSELOT and G. E. ROUSSELOT: 'Effects of Impurities in a Bright-Nickel Bath on the Covering Power of a Chromium Bath.'
Metal Finishing, 1958, vol. 56, Dec., pp. 46–50; 1959, vol. 57, Jan., pp. 58–60.

In introduction, the authors review the nature of the contamination which can build up in bright-nickel solutions during operation, and outline control tests which may be used to determine the effect of such contamination on the uniformity and quality of the chromium coating deposited on the nickel underlay.

The experimental work reported comprised examination of the effects, on final coverage by chromium, of the following impurities, when present in bright-nickel solutions: Cu, Zn, Fe, Cr, Pb, Sn, Cd, Mo. The contaminants were, in most cases, introduced (into a stock bright-plating solution) as dilute sulphate or chloride solutions of the respective metals. (Details are given of the sulphate-chloride-boric-acid basis solution, and of the nature, but not the composition, of the two brightening agents used.) The cathodes were of highly polished brass, standard size (101 mm. × 65 mm.), bent in the middle to an angle of 78°. They were nickel-plated in a 270 cc. Hull cell at 2 amp./dm.², 55°–60°C. After nickel-plating in the contaminated solutions the cathodes were chromium-plated in a standard solution, with a current density of 8 amp./dm.², at 35°. Coverage by chromium is plotted in graphs showing the effect of increasing concentrations of the respective impurities added to the nickel-plating solutions.

From the results, conclusions are drawn with regard to permissible limits of impurity, and notes are added on the possible sources of contamination and on methods which may be used for removal of the individual contaminants.

It is concluded that

'Except for chromium and, to a lesser degree, zinc, cadmium, and molybdenum, which give a very rapid rise of the covering power, most of the metallic impurities of bright-nickel baths cause only a slight and gradual increase in the covering power of the chromium bath.' (A composite graph combines the results for all the metals studied.)

'In the case of all the metallic impurities an alteration in the appearance of the nickel-plating becomes noticeable before the concentration of the impurity causes any great change in the covering power of the chromium bath.' It is therefore argued that when the covering power of a well-balanced chromium solution increases considerably without any great change in the appearance of the nickel deposit, the change may be attributed to organic contamination of the nickel electrolyte. In the author's opinion, such contamination is not only the basic cause of change in covering power of chromium solutions, but is also the most insidious one, since such changes produce no alteration in the appearance of the nickel coating, and the plater is thus deprived of this means of detecting the presence of impurities.

Chromium Plating: Its Significance in Composite Coatings

A. SMART: 'Chromium Plating in Relation to the Corrosion-Resistance of Nickel/Chromium Deposits.'
Electroplating and Metal Finishing, 1959, vol. 12, Jan., pp. 3–10.

This is a detailed and well correlated presentation of information derived from British and American research demonstrating the importance of the quality and thickness of the final chromium coating as a factor affecting the corrosion-resistance of (copper)/nickel/chromium coatings. The arguments are based on the findings reported by

(1) J. EDWARDS, of the British Non-Ferrous Metals Research Association, who studied the mechanism of failure observed in atmospheric tests of composite coatings in which seven types of nickel plating were used as underlay to chromium (see *Product Finishing*, 1958, vol. 11, Mar., pp. 58–66; *Nickel Bulletin*, 1958, vol. 31, No. 5, p. 129).

(2) W. A. WESLEY and B. KNAPP, who concluded that inherent porosity in nickel coatings is much less than has been supposed, and that the view that porosity is the primary cause of failure of nickel deposits (in particular bright nickel) is not substantiated in practice. The conclusion was reached that 'a profitable field for investigation is the influence of greater thicknesses of chromium, on the pitting of the nickel underlayer'. They noted also that the pattern of surface pitting changed with the thickness of the chromium coating (see *Trans. Inst. Metal Finishing*, 1954, vol. 31, pp. 267–84; *Nickel Bulletin*, 1954, vol. 27, No. 5, p. 86).

(3) H. BROWN, M. WEINBERG and R. J. CLAUSS, who, in 1958, reported an extensive investigation of the influence of the properties and thickness of the outer chromium layer, on the behaviour of composite coatings. Their results showed outstanding benefit obtainable by deposition, from high-sulphate baths operated at about 130°F. (54°C.), of an adequate thickness of bright, 'crack-free' chromium (see *Plating*, 1958, vol. 45, pp. 144–50; *Nickel Bulletin*, 1958, vol. 31, No. 5, p. 130).

On the basis of the evidence thus assembled, the author concludes that the plater of to-day will be well advised, in spite of the economic factors involved, to instal plant and standardize practice which will ensure consistent production, under commercial plating conditions, of chromium coatings of quality and thickness which will give the protection required by the user of the products.

In closing, the author makes the following comments with regard to the thickness of nickel required as an underlay: 'When corrosion of a nickel deposit starts at a break in the chromium plating, it proceeds both laterally and vertically. Because of this the

protection afforded by a nickel coat is roughly in geometric proportion to its thickness, that is to say, 1 mil of nickel will last about four times as long as ½ mil, all other conditions being equal. The almost continuous shortage of nickel since the war has resulted in a number of articles intended for outdoor exposure being plated with substantially less nickel than we know to be desirable. Fortunately, the shortage of nickel has now largely disappeared and there seems to be no reason why manufacturers concerned with the lasting appearance of their products should not apply an adequate nickel thickness. It is not suggested that the conclusion to be drawn from these exposure tests is that, by using a thicker chromium coat deposited under the right conditions, we can dispense with part of the nickel.'

'Kanigen' Plating: Properties and Applications

A. McL. AITKEN: 'Some Properties and Applications of Chemically Reduced Nickel.'

Electroplating and Metal Finishing, 1958, vol. 11, Dec., pp. 427–31.

The paper relates exclusively to nickel-phosphorus coatings deposited by means of the 'Kanigen' electroless plating process.

The section covering the properties of such deposits is introduced by reference to the results of spectrographical analysis to determine the amounts of non-metallic and metallic impurities present in the alloy. The hydrogen content was found to be 0·0016 per cent. which might be expected to induce embrittlement in 'Kanigen'-plated steel, and data included in this paper demonstrate that although tensile properties exhibited by 'Kanigen'-plated steel differed insignificantly from those of unplated pickled and polished specimens, such coatings can reduce the fatigue limit of high-tensile steels by approximately 20 per cent. The results of studies of the structure of chemically-reduced nickel are outlined, and a note is given on measurement of its specific gravity. On the assumption that chemically-reduced nickel corresponds to the Ni_3P phase, its X-ray density is 7·91 g./cc.

Experimental comparison of the corrosion behaviour of electroless and electrodeposited nickel coupled with aluminium, stainless steel or mild steel, and exposed to aerated 3 per cent. NaCl (hot aerated tap water was substituted as the exposure medium in the case of the mild steel) showed that the nickel-phosphorus coating was much less porous than the electrodeposited nickel, and that it was approximately similar in electro-potential. It is concluded that, for a given thickness, the corrosion-resistance of the electroless nickel can be expected to be higher than that of electrodeposited coatings.

Brief reference is also made to the results of preliminary work to investigate the suitability of nickel-phosphorus coatings for use as a fluxless furnace-brazing material. Brazing was carried out at 925°–930°C. The strength of the joints indicates that although good gas-tight joints are obtainable, the alloy is not suitable for use in applications where the brazed joint will be under load.

The final section, which reviews some of the applications for which 'Kanigen' coatings have proved suitable, contains notes on the electroless plating of titanium, and the use of the process for plating of gate and butterfly valves, and air driers.

Appraisal of the Electroless Nickel-Plating Process

R. G. GIRARD: 'What Electroless Nickel Can Do for You.'

Plating, 1958, vol. 45, Dec., pp. 1234–8.

The first electroless-plating process capable of commercial exploitation was developed at the National Bureau of Standards, and patented by BRENNER and RIDDELL in 1947. The present paper is written with the aim of reviewing industrial progress since that time: the survey is concerned essentially with the practical aspects of the process and with the commercial advantages it offers *vis-à-vis* deposition of nickel by electrolytic methods. (Results of a comprehensive study of the variables involved in the process were published by DE MINJER and BRENNER, *ibid.*, 1957, vol. 44, Dec.. pp. 1297–305: see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 3, pp. 71–3.)

The review falls conveniently into six sections. In the first, notes are given on physical properties typical of electroless nickel deposits: reference is made to their structure, corrosion-resistance, buffability, hardness, variation of nickel and phosphorus contents (as a function of pH and composition of the solution), ductility, porosity and adhesion. The second section, concerned with equipment used for electroless plating, includes discussion of suitable plating tanks and of heating and ventilation requirements. Hints of value in the preparation of plating solutions and racking of components are given in the third section; buffering agents, agitation, filtration and control of operating conditions form the subject matter of the fourth. In the final section, a review of pre-plating treatments, and notes on solution replenishment and methods of stripping electroless nickel coatings from copper and steel are followed by an appraisal of the process in terms of economics and technical advantages.

Plating of Titanium

T. A. DICKINSON: 'Plating of Titanium and its Alloys. A Note on American Practice.'

Metal Finishing Jnl., 1959, vol. 5, Jan., pp. 24–5, 28.

This article relates to practice developed by some leading U.S. aircraft firms. The major part of the information given is along the lines reported in *Metal Industry*, 1958, vol. 93, p. 78 (see *Nickel Bulletin*, 1958, vol. 31, No. 9–10, p. 262), but more detail is given with regard to activation treatments used on the basis metals, and experience with chromium coatings is recorded at greater length.

X-Ray Measurement of the Thickness of Metallic Coatings

P. S. GOODWIN and C. L. WINCHESTER: 'Continuous X-Ray Measurement of Plating Thickness.'
Plating, 1959, vol. 46, Jan., pp. 41–4.

Although absorption of X-rays has for many years been used to determine the thickness of materials and, more recently, gamma radiation has been successfully applied for this purpose, such methods are not usually applicable to measurement of the thickness of plated coatings, since it is difficult to isolate, from the total radiation, that due to the plating layer.

This paper describes the use of the principles of fluorescence radiation as a means of thickness measurement.

An illustrated description is given of the X-ray fluorescence analyzer, with details of direct and indirect (absorption) methods. The direct method involves a simple determination of the intensity of fluorescence radiation emitted by the coating element itself: the indirect method measures the intensity of radiation emitted by the base material rather than by the coating, the amount of radiation absorbed as it passes through the coating layer being related to the thickness of the coating. Choice of method for a particular measurement depends on three factors: the relative thickness of the coating, mass-absorption coefficient, and density of the coating. Criteria applicable as a basis of selection of method are discussed.

Description of apparatus and technique is followed by a report of results of measurements of coating on tinplate and on galvanized steel.

In discussing the application of the method to the measurement of other types of coating, the author gives tables showing, respectively:

(1) Theoretical maximum thicknesses of (*a*) plating which can be measured by the direct method, and (*b*) representative base materials which can be assessed by the indirect method;

(2) Comparison between chemical and X-ray analyses of electrolytic coatings of copper, brass, nickel and zinc on steel. Results recorded by the two methods show close agreement.

The technical and economic advantages of production control by means of X-ray fluorescence measurement of thickness are emphasized.

NON-FERROUS ALLOYS

Report of the Royal Mint: Nickel-containing Coinage

'Eighty-Eighth Annual Report of the Deputy Master and Comptroller for the Year 1957.'
Published by *H.M. Stationery Office*, 1958; 80 pp. Price 5/-.

The report includes the usual statistical information on United Kingdom silver, cupro-nickel, nickel-brass and bronze coinage, currency withdrawn, assays made, and coinages produced for overseas countries. Details of the activities of the associated Mints in Australia are also given.

In the year 1957 only two coins of entirely new design were produced: one of these was a nickel-brass threepenny piece for use in Jersey. Reference is made also to an order for Iceland one-krona coinage (a denomination not previously struck in the Royal Mint), in which nickel brass was substituted for the aluminium bronze originally used.

New coins, medals and seals struck during the year are illustrated.

Non-Magnetic Copper-Nickel Alloy

E. W. PUGH: 'Completely Non-Magnetic Alloy for Instrumentation in Magnetic Fields.'
Rev. Scient. Instruments, 1958, vol. 29, Dec., pp. 1118–19.

To ensure accuracy of measurements made in the presence of magnetic fields it is often essential that portions of the measuring apparatus shall be fabricated from non-magnetic materials. Typical cases are the balance arms or sample holders used in measurement of magnetic moments, Dewar walls to be used between the poles of a magnet, and torsion fibres and galvanometer suspensions. It is usually sufficient to specify that these items be made of non-ferromagnetic materials such as copper, brass, silver, aluminium or quartz, but occasionally small effects due to ferromagnetic impurities, or even to the intrinsic paramagnetic or diamagnetic moment of such materials constitute a problem. This article describes a copper-nickel alloy (Cu 96·3, Ni 3·7, per cent. by weight) which has a zero magnetic moment at room temperature, and a moment which is less than one-tenth the moment exhibited by pure copper from room temperature down to 2°K. (−271°C.).

Alloying can be accomplished in a standard vacuum furnace (absence of contamination is essential), but the author describes a method which he considers to be of greater general interest, since it can be carried out with limited facilities, in a sealed quartz tube, obviating the need for a vacuum furnace.

A graph shows the susceptibility, per unit mass, of the copper-nickel alloy at temperatures up to 320°K. (47°C.), in comparison with that of alloys containing 10 per cent. more or 10 per cent. less nickel, and with that of pure copper and copper containing 0·0025 per cent. of iron.

Two applications for the alloys are described:

(1) In a sample holder for thin paramagnetic wires, the susceptibilities of which were to be measured at low temperature by the Gouy method.

(2) As sample holder in determination of the anisotropy of thin ferromagnetic films by means of torque measurements.

Structural Changes in (Cobalt)-Nickel-Chromium Alloys by Determination of Magnetic Characteristics

W. WINK and W. JELLINGHAUS: 'Determination of the Magnetic Susceptibility of Nickel-Chromium and Cobalt-Nickel-Chromium Heat-Resisting Alloys.' *Archiv f.d. Eisenhüttenwesen*, 1958, vol. 29, Sept., pp. 567–73.

The paper presents results demonstrating the use of magnetic measurements to indicate differences in the composition of solid solutions and to detect the occurrence of new phases.

The alloys investigated contained 70–80 per cent. of ferromagnetic metals (either nickel or nickel+cobalt in the ratio of 3 : 4, in each case with a small iron content), about 20 per cent. of chromium, and small amounts of various other alloying elements. Some were of low carbon content, others contained about 0·3 per cent. of carbon. The measurements were made on the alloys (*a*) in the solution-treated condition, and (*b*) after further treatment for 5 hours at 800°C., and water-quenching.

Changes in the microstructure of the cobalt-free alloys were only weakly reflected in the magnetic measurements. Alloys containing approximately 40 per cent. cobalt, 30 per cent. nickel and some iron became ferromagnetic at low temperatures, and determination of magnetic susceptibility as a function of field strength and temperature revealed the presence of small amounts of phases which were already ferromagnetic at room temperature. Differences in the composition of the solid solution are reflected in variation in the Curie point and in the relationship of susceptibility to field strength. Study of variation of susceptibility as a function of time of annealing is capable of revealing the presence of an inhomogeneous structure.

Influence of Temperature on the Bursting Pressures of 'Monel' Bursting Discs

See abstract on p. 69.

High-Nickel Alloys Resistant to Hydrochloric Acid, Hydrogen Chloride and Chlorine

See abstract on p. 89.

Symposia on Production of Metal Powders, Compacting and Sintering, Cermets

See abstract on p. 65.

Rapid Determination of Nickel in Brass and Bronzes

H. WIEDMANN: 'Rapid Determination of Tin, Copper, Lead, Iron and Nickel in Red Brass and Bronzes.' *Zeitsch. f. Metallkunde*, 1958, vol. 49, Oct., pp. 545–7.

The paper gives full details of solutions and procedures suitable for rapid and accurate determination, by volumetric and photometric analysis, of tin, copper, lead, iron and nickel in red brass and bronzes. The techniques are designed specifically for application to control of melting practice. It is stated that, by the procedure recommended, determination of nickel can be effected in approximately 10 minutes.

Bright Annealing Furnaces and Ancillary Equipment

See abstract on p. 71.

NICKEL-IRON ALLOYS

Stability of Permanent-Magnet Materials

J. E. GOULD: 'Permanent-Magnet Stability.' *Instrument Practice*, 1958, vol. 12, Oct., pp. 1083–91.

Behaviour of permanent-magnet materials is frequently discussed in relation only to the demagnetization curve or other aspects which fail to give a comprehensive view of overall stability under working conditions: these vary considerably in different applications. New data which are relevant in this connexion have recently been established, and, on the basis of such information and of some hitherto unpublished test results, the author makes a review of the present stage of development and knowledge on the conditions affecting service stability of various types of permanent-magnet materials. As an introduction, a brief review is made of current views on permanent-magnet behaviour, and this is followed by detailed and well-illustrated discussion of the influence of the following factors on magnetization change, i.e., their effect on stability:

(1) *Structural Re-Arrangement*
(e.g., in quenched steels when not aged, or oxidation effects in micro powders).

(2) *Magnetic-Field Effects*
(External fields; surface contacts, causing local field changes; changes in circuit reluctance.)

(3) *Thermal Effects*
(Overall and normal variations in temperature.)

(4) *Elastic Vibration*
(Mechanical shocks and acoustic noise.)

(5) *Nuclear Irradiation*

The effects produced by variables (1)–(5) above are discussed in the light of tests which have been made on various alloys of the nickel-aluminium-(cobalt)-iron alloy and cobalt-steel types, and recommendations are made with regard to precautions which may be taken to promote stability.

Magnetic-Properties/Temperature Relationships in Nickel-Iron Alloys

J. F. FRITZ and J. J. CLARK: 'Effects of Temperature on Magnetic Properties of Nickel-Iron Alloys.' *Electrical Manufacturing*, 1958, vol. 62, Nov., pp. 135–9.

Environmental conditions now imposed on electrical equipment are becoming increasingly severe: thermal variations involved in some types of service present a particularly difficult problem in relation to magnetic

devices, in which frequently nickel-iron alloys of various types are used in many vital components.

This article reports results of a study undertaken, in the Materials Engineering Department of Westinghouse Electric Corporation, to obtain data suitable for use in design of new magnetic devices, and to provide information which could be applied in temperature compensation of existing designs. The research was sponsored by Wright Air Development Center.

Tests were made on six commercial nickel-iron alloys, representative of types in general use: nominal compositions are shown below:

Trade Name	Composition		
	Ni %	Fe %	Mo %
'Hipernik V'*	50	50	—
'Hipernik'	50	50	—
'Deltamax'*	50	50	—
4-79 Mo-'Permalloy'	79	17	4
'Supermalloy'	79	16	5
'Hymu 80'	79	17	4

* Grain-oriented to obtain 'square-loop' characteristics.

The test samples were toroids wound from 0·002-in. (0·05-mm.) tape, with average dimensions of $2 \times 1\frac{1}{2} \times \frac{1}{4}$ in. ($5 \times 3{\cdot}75 \times 0{\cdot}6$ cm.). Measurements were made by standard ballistic testing methods; the magnetizing current was changed discontinuously, and the resulting flux change was measured by a ballistic galvanometer used as a fluxmeter. At each test temperature (between $-60°$ and $+250°$C.) a normal magnetization curve was determined and residual induction (B_r) and coercive force (H_c) were measured. The tests were first performed at intervals of increasing temperature, then repeated at decreasing temperatures, to determine temperature hysteresis or ageing of the materials.

The results are shown in curves, giving, for each alloy, normal magnetizing curves, at increasing temperatures; normal magnetizing curves at decreasing temperatures; coercivity *vs.* temperature; saturation induction, remanence *vs.* temperature. Comments are made on the characteristics of the respective alloys, as exhibited by the graphical data.

A related article (*ibid.*, pp. 111–34) contains a review of electronic materials and components for use in extreme environments. The survey deals with major problems involved in service at ultra-high temperatures, in association with nuclear radiation, and in other abnormal conditions, with specific reference to the effects of such environments on the efficiency of electronic materials. The review contains extensive tabular data, and is supported by a *bibliography* of 50 references.

Nickel-containing Permanent Magnets for Use at Elevated Temperatures

G. SIDERIS: 'Hard Magnets for 500°C.'
Electronics, 1959, vol. 32, June 9, p. 63.

Development of nuclear plant and of new types of military aircraft and missiles has resulted in a demand for permanent magnets capable of retaining a substantial proportion of their magnetic properties at 500°C. Components in which such magnets might be employed at elevated temperatures include transducers, travelling-wave tubes, magnetrons plus servo components and other small motors.

This brief note gives the result of investigations carried out by Armour Research Foundation and Stanford Research Institute on the effect of temperature on typical nickel-aluminium-cobalt-iron-base magnet materials. The curves shown indicate the satisfactory retention of magnetic remanence in these alloys at temperatures up to approximately 500°C. A reminder is given that cobalt will become radioactive in a nuclear environment and that this characteristic should be considered in design of nuclear plant in which permanent-magnet or other cobalt-containing alloys are used.

Influence of Method of Demagnetization on Reversible Permeability in Nickel-Iron Alloys

R. C. JACKSON, E. W. LEE AND A. G. H. TROUGHTON: 'The Influence of the Method of Demagnetization on the Reversible Permeability of a High-Permeability Nickel-Iron Alloy.'
Brit. Jnl. Applied Physics, 1958, vol. 9, Dec., pp. 495–7.

It is well known that the behaviour of a ferromagnetic substance in low and moderate fields depends on its magnetic and thermal histories, and evidence has recently been presented indicating that the low-field properties of a ferromagnetic substance may depend also on the manner in which it has been demagnetized.

This paper reports a study on high-permeability alloys of the nickel-iron-copper-molybdenum type. The results of measurements of reversible permeability confirm that dependence upon biasing field is affected by the method of demagnetization used. Initial permeability after a.c. demagnetization is always greater than after thermal demagnetization, indicating that some other effect also must be present. It is considered that this genuine effect is caused by a change in the number of domain walls.

CAST IRON

Underground Corrosion of Metals: Review

See abstract on p. 91.

Determination of Nickel in Cast Iron by Absorptiometric Methods

See abstract on p. 72.

CONSTRUCTIONAL STEELS

Deoxidation and Desulphurization of Steel by Treatment with Nickel-Magnesium Alloy

E. PIWOWARSKY, W. PATTERSON and F. W. ISKE: 'Improving the Impact Properties of Cast Bessemer Steel.'

Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen, Report 461, 1957; 41 pp.

The investigation reported was undertaken to ascertain the possibility of improving the properties (especially impact-resistance) of Bessemer steel by treatment with deoxidizing and desulphurizing media of various types. Consideration of the mechanism of deoxidation and desulphurization led to the conclusion that a dual effect might be obtained by the use of an agent containing magnesium, and experience gained in the use of magnesium-containing materials for production of S.G. iron was utilized in selecting the type of addition medium.

The experiments comprised treatment by the following methods:

(1) Addition, to the molten iron, of various amounts of 15-85 magnesium-nickel alloy or of magnesium-copper-aluminium alloy.

(2) Treatment of the blown steel by addition of elemental magnesium, in a pressure ladle.

(3) Addition of magnesium-nickel or magnesium-iron-silicon alloy to the stream of iron as it flowed from the cupola immediately prior to blowing.

(4) Introduction of magnesium-iron-silicon alloy into the converter during blowing.

(5) Treatment with magnesium-aluminium and calcium-aluminium alloys by addition before and after blowing.

The effects of the various additions were assessed by chemical analysis of the treated steel and by the results of impact tests on notched specimens, at room and at sub-zero temperatures.

The authors' conclusions are summarized below:

Treatment of the molten iron with the magnesium-nickel alloy may be effected without risk of dangerous reaction. Such treatment considerably lessened the notch-sensitivity of the steel at room temperature and lowered the temperature range in which the tough-to-brittle transition occurred. The degree of desulphurization achieved was governed by the amount of alloy used: optimum results were obtained by addition to the iron from the cupola before its conversion to steel.

Treatment by addition of elemental magnesium, in a pressure ladle, also resulted in improvement in impact characteristics, but the desulphurizing effect was less potent. Treatment with magnesium-iron-silicon alloy slightly increased impact-resistance, but desulphurization was negligible. The use of magnesium-aluminium and calcium-aluminium alloys proved deleterious, because of the high aluminium content thus introduced into the steel.

Vacuum-Melting of Steel: Equipment, Procedure and Applications

See abstract below.

Corrosion of Nickel-Copper-Phosphorus Steels in Seawater

C. P. LARRABEE: 'Corrosion-Resistant Experimental Steels for Marine Applications.'

Corrosion, 1958, vol. 14, Nov., pp. 501t–4t.

This paper was abstracted, from a preprint version, in *Nickel Bulletin*, 1958, vol. 31, No. 11, p. 293.

Underground Corrosion of Metals: Review

See abstract on p. 91.

Bright Annealing Furnaces and Ancillary Equipment

See abstract on p. 71.

Inert-Gas Consumable-Electrode Welding of Steels in Thin Section

See abstract on p. 71.

HEAT- AND CORROSION-RESISTING MATERIALS

Vacuum-Melting of Steel: Equipment, Procedure and Applications

H. C. CHILD and G. T. HARRIS: 'Vacuum-Melting of Steels.'

Jnl. Iron and Steel Inst., 1958, vol. 190, Dec., pp. 414–31.

Until relatively recently the vacuum obtainable in vacuum-melting furnaces was far from satisfactory, and the vacuum-melting process had to be regarded rather as protective-atmosphere melting than as a method of vacuum-purification. With the construction of furnaces capable of operating at pressures of the order of 10^{-3} mm. of mercury, however, production of high-purity materials by vacuum-melting became feasible, and the technique has since been widely applied to development of materials with improved properties. This paper reviews the factors involved in the application of vacuum-melting to steels.

The review is in three sections. In the first, the authors describe (with cut-away diagrams) the equipment used in vacuum-induction and consumable-electrode vacuum-arc processes. The second section considers the relative advantages and limitations of

vacuum-melting by these techniques, while the third gives examples of the improved properties exhibited by vacuum-melted materials.

The authors' assessment of the vacuum-induction process is mainly in terms of its use as a method of purifying the base charge by degasification (which can then be followed by introduction of any desired reactive or volatile additions), as a means of re-melting, under inert conditions, previously vacuum-melted scrap, or as a method of producing materials of closely controlled composition. Critical discussion of vacuum-arc melting leads to the conclusion that its advantages lie in the absence of furnace refractories and in the minimized segregation and porosity resulting from progressive freezing of the ingot.

The final section of the paper is concerned with improvements achieved in the properties of vacuum-melted, *vis-à-vis* air-melted, materials, and the fields of application for vacuum melting. In the U.S.A. vacuum-induction melting has been applied principally to the production of nickel-base alloys for gas-turbine blades: in a résumé of the properties reported as being obtainable in American materials of this type the authors refer to comparative data on British vacuum-melted alloys, *inter alia*, those of the 'Nimonic' series. A similar comparison of British and American materials is made in discussion of the characteristics of vacuum-melted carbon-chromium ball-race steel, and of steels used for disc forgings. (The austenitic heat-resisting chromium-nickel steels employed for disc forgings in the U.S.A. have only recently aroused interest in the U.K., and discussion of this aspect of vacuum-melting relates mainly to the martensitic chromium steels. Data are, however, given on properties achieved in a disc fabricated from the complex steel 'G 18B', which contains nickel, chromium and cobalt, together with small amounts of other elements.)

Great difficulty has been experienced in precision casting of heat-resisting alloys containing critical amounts of elements such as titanium and aluminium, not only on account of the loss of these elements occurring during melting, but also as a result of contamination by their oxidation products TiO_2 and Al_2O_3. These difficulties are avoided by melting and casting the alloys *in vacuo*: the efficacy of this procedure is illustrated by comparing the properties of vacuum-cast materials with those typical of air-cast alloys.

In the development of ultra-high-tensile steels for aeronautical applications the feasibility of obtaining, by vacuum-melting, a material of high ductility, having a minimum of non-metallic inclusions, has stimulated research in this connexion: current progress is briefly reviewed. The paper ends with a brief reference to the potential usefulness of two new vacuum processes: skull-melting and electron-bombardment melting.

Among the nickel-containing materials to which reference is made, in one or more sections of the paper, are the nickel-base alloys 'Waspalloy', 'M-252', 'Udimet 500', 'Nimonic 80A', 'Nimonic 100', 'GMR-235', 'Guy Alloy', 'Inco 713', 'G-64' and 'C-242'.

Sigma Phase: Nature, Occurrence, Effects

R. ERGANG, G. GÜNTHER and H. WEIK: 'The Sigma Phase in Iron-Nickel-Chromium Alloys.'

Stahl und Eisen, 1959, vol. 79, Jan. 8, pp. 46–51.

A documented review of information, supported by reference to 60 *items of world literature*. The subject is dealt with in sections covering, respectively, detection of sigma phase; the Fe-Ni-Cr constitutional diagram; rate of formation of the phase and factors affecting it; influence of previous history of the alloys; change in mechanical properties resulting from precipitation of sigma phase; mechanism of formation of sigma, and its structure; influence of alloy additions on susceptibility to formation of the phase, and the mutual relation of addition elements when present in varying combination: influence of sigma phase on the corrosion-resisting characteristics of iron-chromium-nickel alloys.

Creep-Resistance of Austenitic Steels and Alloys

K. BUNGARDT: 'Creep Tests on Austenitic Steels and Alloys.'

Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen, *Report* 456, 1958; 24 pp. + tables and figures.

The data presented and discussed in this interim report relate to a comprehensive series of tests carried out under the aegis of Verein Deutscher Eisenhüttenleute, Arbeitsgemeinschaft Deutscher Turbinenfabriken im Verein Deutscher Maschinenbauanstalten and Vereinigung der Grosskesselbesitzer und des Wasserrohrkesselverbandes. The main aim was to obtain data on the creep behaviour of austenitic materials, to serve as a basis for design of industrial power plant operating at high temperatures for long periods and to aid in development of improved heat-resisting materials.

The composition and room- and high-temperature mechanical properties of the wide range of steels and alloys tested are tabulated, together with details of heat-treatments and data derived from notch-impact tests, at room temperature, on specimens which had been heated for 1000 hours at various elevated temperatures. On the basis of composition, the materials studied may be classified as follows:

Chromium-Nickel Steels (*Iron content* >50%)

All the steels were stabilized with niobium or titanium, and some contained other alloying additions, e.g., boron, cobalt, molybdenum, nitrogen, vanadium or tungsten.

Chromium-Manganese Steels

These steels contained also either vanadium or nitrogen.

Chromium-Cobalt-Nickel-Iron Alloys (*Iron* <50%)

The composition range was designed to provide representative coverage of German and foreign commercial heat-resisting alloys. In certain alloys the iron content was below 10 per cent., and in some cases the basis constituents were supplemented by

addition, in various combinations, of carbon, molybdenum, vanadium, tungsten, niobium, tantalum, titanium and nitrogen.

Nickel-base Alloys

Only one alloy of this type was included: it contained about 20 per cent. chromium, 2 per cent. titanium and 0·6 per cent. aluminium.

The influence, on creep behaviour, of the following factors was studied:

(1) Composition.

(2) Use of notched specimens.

(3) Cold-working or a combination of hot- and cold-working.

(4) Heat-treatment. (The influence of solution-treatment at different temperatures was determined on a chromium-cobalt-nickel-iron alloy; the other alloys were tested in the condition obtained by normal commercial heat-treatment.)

(5) Welding. (Comparative creep tests on welded and unwelded specimens of the same heat related mainly to the chromium-nickel steels.)

The creep tests were carried out at temperatures of 600°, 650°, 700°C. The data so far obtained are presented *in extenso*, in terms of creep strength for, and 0·2, 0·5 and 1 per cent. creep at, 1000, 10000 and 20000 hours. From consideration of these data and the other factors which were taken into account during the investigation, the author draws the following conclusions:

At about 600°C. the creep properties of the niobium-stabilized austenitic chromium-nickel or chromium-nickel-molybdenum steels were superior to those of similar steels stabilized with titanium: at higher temperatures, however, this difference was less clearly marked. In the niobium-stabilized straight-chromium-nickel steels increase in the nickel content from 10 to 13 per cent. proved beneficial.

Raising the nickel content of the niobium-stabilized chromium-nickel-molybdenum steels had practically no effect on creep, but did result in improved ductility in creep. A conjoint addition of niobium, vanadium and nitrogen was effective in improving creep properties of these steels at temperatures up to about 650°C. After long-time testing at 700°C. there was no fundamental difference among the various steels. Small additions of cobalt and tungsten had little effect on the properties of the chromium-nickel-molybdenum steels. It is recommended that vanadium-bearing steels should not be used at temperatures above 600°C.: at higher temperatures severe scaling can be expected, particularly in conditions where access of air is restricted.

The creep behaviour of niobium-stabilized steels of 16-13 chromium-nickel and 16-13-2 chromium-nickel-molybdenum types was considerably improved by small additions of boron, and the influence of boron was favourable also in more complex steels.

The creep characteristics of the chromium-cobalt-nickel-iron alloys improved with increase in cobalt and nickel contents and with the amount of carbide-formers present. Addition of titanium produced a significant improvement in creep properties, particularly in the initial stages of testing, but was less efficacious as the duration of test was prolonged. A tantalum-containing alloy of this group exhibited the highest creep-resistance of all the materials tested.

The degree to which the effects of mechanical working (at various temperatures) are reflected in creep behaviour was found to depend on the composition of the material. Beneficial effects were observed with the boron-containing niobium-stabilized 16-13-2 chromium-nickel-molybdenum steel and with an alloy containing cobalt 20, nickel 20, chromium 17, molybdenum 3, tungsten 2·5, niobium 1·3, vanadium 1, nitrogen 0·15, carbon 0·1, per cent., remainder iron.

Ductility was assessed on the basis of elongation and reduction in area at fracture and by creep tests on notched specimens. The behaviour of the various solution-treated or hardened steels studied did not differ sufficiently to permit any specific correlation with composition. With the exception of the chromium-manganese steels, values for elongation and reduction-in-area fell more or less rapidly at first, though in some cases they recovered somewhat with longer testing times. None of the steels, whether solution-treated or hardened, displayed any pronounced tendency to brittle fracture. Mechanical working caused a fall in creep ductility, and with the precipitation-hardening alloys raising of the solution temperature acted in a similar sense, although creep-resistance improved.

The sparsity of the data so far available permits no definite conclusions with regard to the creep behaviour of welded specimens. Rupture in most specimens occurred in the transition zone between the weld and the basis metal.

Fatigue, Creep and Structure of Nickel-base High-Temperature Alloys

V. A. PARFENOV: 'Influence of Stress on the Ageing Processes of Alloy EI 437 at 750°C.'

Metallovedenie i Obrabotka Metallov, 1955, vol. 4, pp. 16-19.

Study of the microstructure and fracture characteristics, after creep and fatigue tests, of specimens of a nickel-chromium-base alloy hardened with aluminium and titanium. The material was examined in the solution-treated and in the aged conditions.

V. A. PARFENOV: 'Relation between the Endurance and Long-Time Strength of (Nickel-base) Alloys at Elevated Temperatures.'

Ibid., 1957, vol. 6, pp. 17-23.

Fatigue and creep data are plotted on stress-rupture or stress-temperature graphs for the nickel-chromium-titanium-tungsten-molybdenum alloy EI 617, the nickel-chromium-aluminium-titanium alloy EI 437

and a high-alloy steel (EI 395). Factors influencing deformation were investigated by microscopical examination.

V. A. PARFENOV: 'Characteristics of Fatigue Failure of (Nickel-base) Alloys at High Temperatures.'
Ibid., 1958, vol. 2, pp. 19–22.

Study of fatigue behaviour of, and structural changes in, heat-resisting alloys subjected to cyclic loading at various temperatures.

For summaries of the results of the investigations described in the three papers see *Metallurgical Abstracts*, 1958, vol. 26, Dec., pp. 307 and 308.

Creep-Strength of Nickel-Molybdenum-Chromium-Iron Alloys

T. K. ROCHE: 'The Influence of Composition upon the 1500°F. Creep-Rupture Strength and Microstructure of Molybdenum-Chromium-Iron-Nickel-base Alloys.'
U.S. Atomic Energy Commission, Oak Ridge Nat. Laboratory Report 2524, undated; 110 pp.

Progress in the development of nuclear power reactors fuelled with molten uranium-bearing fluoride salts has been to a great extent contingent on development of a material of construction which would combine satisfactory resistance to the severe operating conditions with the necessary nuclear properties. Work in this connexion has shown that, of the commercial alloys available, the 80–14–6 nickel-chromium-iron alloy 'Inconel' and the 67–28–5 nickel-molybdenum-iron alloy 'Hastelloy B' offered the greatest potential. Both possessed desirable characteristics, but neither was fully satisfactory: the high-temperature strength of 'Inconel' was found to deteriorate as a result of exposure to the molten fluoride salts, while 'Hastelloy B', though virtually unaffected in this way, suffered a marked decrease in ductility after extended service in the temperature range 1200°–1600°F. (650°–870°C.). A compromise solution to the problem was sought, at the Oak Ridge National Laboratory, in nickel-base alloys containing strengthening additions of 15–20 per cent. of molybdenum and minor amounts of other elements (see, for example, PRESTON, FOE and GRANT, *ibid.*, *Report* 2520; *Nickel Bulletin*, 1958, vol. 31, No. 12, p. 343). Assessed on the basis of strength, workability, weldability and corrosion- and oxidation-resistance, the most suitable alloy was that designated 'Inor-8', the compositional limits of which are given as: molybdenum 15–17, chromium 6–8, iron 4–6, carbon 0·04–0·08, per cent., balance nickel. It was thought advisable to investigate the effects, on strength and microstructure, of varying the composition of alloys within a range wide enough to include that of 'Inor-8', i.e., molybdenum 10–20, chromium 5–10, carbon 0·6, manganese 0·5, aluminium 0·5, per cent., balance nickel. The results of this investigation are recorded in the present report.

Two series of alloys were prepared for testing. In the first the molybdenum, chromium and iron contents were varied, and aluminium and manganese were added as malleablizing agents, the carbon content being maintained at constant level. The carbon content, however, was subsequently found to mask the effects of variations in chromium and iron, and no intentional carbon or malleablizing additions were therefore made to the second series of alloys, which were prepared from materials of very high purity.

The scope of the investigation is indicated below.

(1) Creep-rupture tests were carried out, in an argon atmosphere, at 1500°F. (815°C.) under a stress of 10,000 p.s.i. (4·5 t.s.i.; 7 kg./mm.^{2}), on specimens annealed at 2100°F. (1150°C.). Creep-rupture strength was assessed on the basis of time to produce a strain of 1, 2, 5, 10 and (in the case of the high-purity alloys) 0·5 per cent.

(2) A study was made of the influence, on the results, of grain size.

(3) The age-hardenability of the carbon-containing alloys was assessed on the basis of hardness measurements carried out on specimens aged for 5, 25, 50, 100 and 1000 hours at 1500°F. (815°C.). In addition, one specimen of each of the high-purity alloys was aged for 100 hours at the same temperature, to determine its equilibrium structure.

(4) To confirm the identification of certain precipitates as carbide particles, some of the alloys were decarburized and, after ageing, their microstructures were compared with those of untreated alloys.

(5) Each alloy was subjected to metallographic examination in the as-cast and, where applicable, in the aged and decarburized conditions. A metallographic study was made also on sections taken from a creep-rupture specimen of each alloy.

The author's results may be summarized as follows.

The carbon-containing alloys could, it was found, be classified, on the basis of increase in creep-rupture strength, into three groups corresponding to increase in the levels of molybdenum studied: 10, 15, and 20 per cent. Within these groups the principal factors affecting the strength of the alloys were the solid-solution elements, ageing reactions, the presence of M_6C-type carbides in the microstructure, and grain size. The relative strengthening effect of each of these factors varied, however, with the individual group. Increase in the relative strength of the alloys is attributed mainly to the combined effects (solid-solution strengthening and increase in the amounts of dispersed M_6C-type carbides) of addition of molybdenum. Only one exception to this finding was noted: the 20–7–10 molybdenum-chromium-iron alloy precipitated a non-carbide phase which had a pronounced effect on creep-rupture strength in the later stages of testing. The strengthening effects of chromium and iron could not be established with certainty.

Times to achieve a specified amount of strain prior to rupture appeared more valid as a criterion for correlation of the data obtained than did time to rupture.

Although carbide precipitation and variation in grain size complicated interpretation of data derived from tests on the high-purity nickel-molybdenum-chromium alloys containing 15 per cent. molybdenum, in the other alloys the strengthening effect of chromium was found to be significant in the range 5–10 per cent. and pronounced at the 10 per cent. level. The strengthening effect of additions of up to 10 per cent. of iron to a nickel-base alloy containing 15 per cent. molybdenum, 7 per cent. chromium was negligible.

Consideration of the data obtained leads the author to confirm the suitability of the composition originally specified for the alloy 'Inor-8'. Any increase in the molybdenum content up to the limit of solubility would be made at the expense of workability and would result in only a slight increase in strength. A chromium content within the stipulated range is necessary for satisfactory oxidation-resistance. Introduction of iron within the limits given is not considered to be deleterious.

High-Temperature Deformation of Chromium-Nickel Austenitic Steel

C. CRUSSARD and R. TAMHANKAR: 'High-Temperature Deformation of Steels: A Study of Equicohesion, Activation Energies and Structural Modifications.'

Trans. Metallurgical Soc., Amer. Inst. Mining and Metallurgical Engineers, 1958, vol. 212, Dec., pp. 718–30.

The concept of an equicohesive temperature was introduced by Jeffries as a result of the finding that at low temperatures the grain boundaries of a material constitute hard zones acting as obstacles to plastic deformation, whereas at high temperatures they are soft, and deform or crack more readily than the grains. Consequently, at some intermediate temperature, the 'temperature of equicohesion', grains and grain boundaries should be of equal strength.

Equicohesion may be studied from two aspects: resistance to plastic deformation; resistance to fracture, or the mode of fracture (inter- or transgranular). One of the aims of the work now reported was to determine the extent to which the two criteria are correlative. The overall purpose was to study structural modifications occurring during plastic deformation at temperatures below and above the temperature of equicohesion, and, by determination of activation energies, to interpret such changes in terms of the theory of dislocations previously outlined by Crussard.

The main programme of tests (tensile, creep, and torsion tests, and measurement of internal friction and elastic modulus) was carried out on Armco iron and on an austenitic steel, 'ATV', containing nickel 36, chromium 10·2, per cent. The chromium-nickel austenitic steel 'Nicral D' was included, for purposes of comparison, in the metallographic phase of the investigation, which involved study of structural modifications by means of X-ray, and optical- and electron-microscopical techniques. The results, which are presented in detail, are shown to be in agreement with the theories advanced.

Recrystallization in Nickel-Chromium-Cobalt-base Alloys

E. Z. KAMINSKII, V. M. ROZENBERG and N. T. TRAVINA: 'The Influence of the Constituents of an Alloy on the Kinetics of the Recrystallization of Nickel, Nickel-Chromium, and Nickel-Chromium-Cobalt.'

Problemy Metalloved. i Fiz. Metal, Inst. Metalloved. Fiz. Metal, Sbornik Trudov, 1958, No. 5, pp. 503–21.
Chemical Abstracts, 1958, vol. 52, p. 19,802.

'Fifty-four different nickel alloys, containing chromium 1–21, cobalt 1–60, aluminium 1–5, titanium 1–5, tungsten 3–10, and molybdenum 2–8, per cent., were investigated with regard to their recrystallization temperatures at different times of tempering. Eleven graphs show the relation of recrystallization time and content of the minor alloy constituents.'

Influence of Temperature on the Bursting Pressures of Nickel, 'Monel' and Stainless-Steel Bursting Discs

See abstract on p. 69.

Dispersion-Hardening of Sintered Nickel-Chromium Alloy

E. GREGORY and C. G. GOETZEL: 'Some High-Temperature Properties of Nickel-Alloy Powder Extrusions containing Non-Metallic Dispersions.'

Trans. Metallurgical Soc., Amer. Inst. Mining and Metallurgical Engineers, 1958, vol. 212, Dec., pp. 868–74.

The outstanding elevated-temperature properties exhibited by components made from sintered aluminium powder (S.A.P.) have aroused interest in the possibility of extending the advantages achieved by dispersion hardening to metals or alloys capable of operating at much higher temperatures. Techniques by which uniform dispersion of a hard phase may be achieved are briefly reviewed in the introduction to the present paper. In much of the earlier work done in this connexion an elemental-metal matrix had been used: the investigation now described was carried out to study effects obtainable with an alloy matrix. The material selected was an 80–20 nickel-chromium alloy fine powder. Particles of the alloy were mechanically mixed with the hardening constituent, present in each case in a volume percentage of 17·5. The composite was then compacted under a pressure of 30 tons/sq. in. (47 kg./mm.^{2}) and sintered in dry hydrogen, to produce a billet which was sheathed in mild steel, prior to extrusion, in order to prevent oxidation during final densification. The extruded specimens were subjected to metallographic examination, impact tests at room temperature, and stress-rupture tests at 1500° and 1800°F. (815° and 980°C.).

The influence of the following variables was studied:

(1) Blending the initial powders by
   (*a*) simple mixing in acetone suspension in a domestic food blender;
   (*b*) milling in water, in a centrifugal type of ball mill;
   (*c*) dry milling, in a centrifugal ball mill in the presence of stearic acid.

(2) Use of the following powders for the hardening phase: magnesia, titanium carbide, thoria and two grades of alumina.

(3) Sintering at 2000° and 2280°F. (1093° and 1248°C.).

Microscopical examination showed that the structures of alloys hardened with oxide additions were similar to those of S.A.P. materials. Other conditions being equal, sintering at the lower temperature yielded finer dispersion and resulted in higher rupture strengths. Changes in the various production stages, or variation in the material used for the hardening phase, were found appreciably to affect the properties obtained. Some of these changes are reflected in the microstructure; others, however, are not shown up by optical examination. Interpretation of structure by means of the electron microscope, while yielding more useful information, also required some circumspection. Care is therefore recommended in using structure as a criterion of strength.

Stress-rupture tests at 1500°F. (815°C.) showed that addition of oxides or titanium carbide resulted in appreciable improvement in strength. A 16 per cent. concentration of titanium carbide increased the stress for a 100-hour life from 4,800 to 14,000 p.s.i. (2 to 6 t.s.i.; 3·5 to 10 kg./mm.^{2}), but it is believed that in this case the solubility of carbide in the matrix might have played a more important rôle than dispersion hardening.

The tests at 1800°F. (980°C.) showed that alumina and magnesia additions, mixed with the alloy by centrifugal milling, had no effect on stress-rupture characteristics. A thoria content of 17·5 vol. per cent., dispersed by means of the food blender, increased the 100-hour rupture life from 1800 to 5000 p.s.i. (0·8 to 2·2 t.s.i.; 1·25 to 3·5 kg./mm.^{2}) and the stress-rupture properties of the dispersion-hardened alloy were equivalent to those of widely used wrought nickel-base alloys. The ductility and room-temperature impact-resistance exhibited by some of the composites were, on the other hand, low compared with those typical of conventional materials. The high strength of the thoria-containing materials at 1800°F. (980°C.) can be interpreted in terms of the high thermodynamic stability of the oxide: it is considered equally likely, however, that the prolonged ball milling to which the thoria was subjected may have affected the surface of the particles in such a way as to increase tendency towards bonding and thereby improve the properties of the cermets.

The results also indicate that the blending technique used may influence the properties to a greater extent than was previously thought to be the case.

Symposia on Production of Metal Powders, Compacting and Sintering, Cermets

See abstract on p. 65.

Bonding of Cermets to Metals

See abstract on p. 69.

Nickel-containing Electrical-Resistance Materials: Properties and Design Data

HENRY WIGGIN AND CO., LTD.: 'Wiggin Electrical-Resistance Materials.'

Publn. 1084, Dec. 1958; 140 pp.

As a result of continuous improvement in production techniques and the introduction of new alloys, the electrical-resistance materials produced by Messrs. Henry Wiggin and Co., Ltd., now offer a range of properties capable of meeting the requirements of practically every application in which electrical-resistance heating is used.

This publication, which comprises a complete revision and amplification of the earlier handbook produced by the Company, contains data and information designed to facilitate selection of the most suitable materials for specific applications. All graphs and other data are based on knowledge gained by service experience as well as laboratory tests.

The publication covers grades 'C', 'S', 'B', 'F' and 'H' of the nickel-chromium-base alloys of the 'Brightray' series, the nickel-copper alloys 'Ferry' and 'Monel', and 'A nickel'. The scope of the information contained in the sections and subsections is indicated below.

Compositions and Physical, Mechanical and Electrical Properties of the Materials Reviewed

General Information

Specific Resistance; Temperature Coefficient of Resistance; Temper and Finishes Available; Special Grades ('HTC Nickel', 'TC Ferry', Oxy-insulated finish); Tolerances to which supplied; Reels and Coils—Sizes, Weights, etc.; Quality, Development, Testing and Inspection.

Design and Calculation

Domestic heating; Terminations, Leads, Connections, etc.; Furnace Elements; Diagrams for 'Brightray' C and S, 'Ferry', and 'A nickel', relating straight wire temperature to wire size and current.

Tabular Data on Resistance and Current-carrying Capacity of Nickel, 'Ferry' and various alloys of the 'Brightray' series, in the form of Wire, Strip and Tape.

Corrosion Tables, Formulae and Other General Information for Reference in Using Electrical-Resistance Elements.

See also:

HENRY WIGGIN AND CO., LTD.: 'Some Properties of Wiggin Electrical-Resistance Materials.'

Publn. 1616*, 1959; 35 pp.

This booklet is an abridged version of the publication referred to in the preceding abstract. The

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design data and tables have been omitted and the brochure is intended rather as an introduction to the materials and applications covered than as a reference book for the electrical engineer.

Behaviour of Nickel-Chromium Electrical-Resistance Alloys in Nitrogen

H. PFEIFFER: 'The Behaviour of Electrical-Resistance Alloys in Nitrogen and Nitrogen-containing Gases.' *Archiv f.d. Eisenhüttenwesen*, 1958, vol. 29, Sept., pp. 575–84.

Although the service life of an electrical-resistance alloy at high temperatures is determined mainly by its resistance to oxidation, in certain applications adequate resistance to attack by other gases, such, for example, as are present in controlled furnace atmospheres, is often of vital importance. In this paper particulars are given of a test apparatus developed to determine the resistance of such alloys to attack by any specific gas or mixture of gases at high temperatures.

The alloys are exposed to the gaseous atmosphere in the form of wire which is heated to the required temperature by passage of an electric current. A detailed description is given of the set-up, and the use of the technique is exemplified by presentation of results obtained in investigation of the behaviour, in the presence of nitrogen and ammonia, of alloys of 80–20 nickel-chromium, 50–30–20 iron-nickel-chromium and 65–30–5 iron-chromium-aluminium types.

It was found that the nickel-chromium-base alloys have, in general, a longer life in commercial and chemically pure grades of nitrogen than in air; for iron-chromium-aluminium-base alloys the reverse is true. The life of the nickel-chromium-base alloys in ammonia exhibited a pronounced increase as the test temperature was raised: at temperatures below 1150°C. ammonia, or preferably cracked ammonia, is therefore considered suitable for use as a protective atmosphere. The finding that the life of the iron-chromium-aluminium alloys in ammonia was not governed by temperature in the range 700°–1200°C. is discussed. Nitrogen attack observed on the same series of alloys is attributed to internal nitriding, and is explained in terms of a mechanism similar to that of internal oxidation.

Metallographic examination of the iron-chromium-aluminium alloys showed that two nitrides were present: the hexagonal AlN and a cubic modification corresponding to CrN.

'Brightray'-coated Exhaust Valves

HENRY WIGGIN AND CO., LTD.: ''Brightray'-coated Exhaust Valves.'

Publn. 1336*, 1958; 8 pp.

During the war it was realized that improvement in output and thermal efficiency of aero engines was contingent on increase in the octane rating of the fuel, which necessitated an increase in the tetra-ethyl/lead content. At the operational temperatures used, this caused severe corrosion of the valve steels. Efforts to take advantage of the excellent resistance of the 80–20-type nickel-chromium alloys to the combustion products of leaded fuels culminated in the development of a special grade of 'Brightray' which, throughout the war, was used to surface most aero-engine valves and to reclaim exhaust valves of heavy transport vehicles. This wartime practice has since been extended, so that in addition to its continued use for aero-engine exhaust valves, this treatment is being increasingly employed on valves for diesel engines, especially in those operating on heavy fuels.

The coating process involves deposition, by oxy-acetylene welding, of the 80–20 nickel-chromium alloy 'B.A.C. Brightray', on the seat, rim and edge of the crown of the valve. As applied to valves for road vehicles, the process comprises three stages: preparation of the head of the valve; deposition of the coating; machining and grinding of the coated valve head. All three stages are described and illustrated in the brochure.

Residual Oil-Ash Corrosion in Gas Turbines

W. TIPLER: 'The Present Position and Future Prospects concerning the Use of Residual Fuel Oils in Gas Turbines.'

Oil Engine and Gas Turbine, 1958, vol. 26, Mid-Nov., pp. 279–83; Mid-Dec., pp. 317–20.

The salient features of a paper presented at a meeting of the International Gas Turbine Conference held at Mons in June 1958 are outlined in the two issues of the journal.

The paper is divided into three sections: the first, which describes the structural features of the multi-head combustion chamber and discusses its merits and limitations in relation to residual-fuel-oil operation, is reviewed in the November issue. The other sections, dealing with fuel-oil-ash deposition and its corrosive effect, and with the application of gas-turbine experience to free-piston engines, are summarized in the December article.

The problem of fuel-ash corrosion is recognized as the main factor preventing efficient and competitive use of the gas turbine in industrial applications, since it can be minimized only by restricting the inlet operating temperature to an uneconomic level. Maximum operating temperature largely governs the extent to which deposition and corrosion occur, and on this basis the author discusses the problem, and the attempts which have been made to combat it. The subject is considered in sections relating to: (1) uncooled turbine blading with gas-inlet temperatures not higher than 650°C.; (2) uncooled blading with inlet temperatures exceeding 650°C.; (3) cooled turbine blading with very high inlet temperatures.

At the close of the paper brief reference is made

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to the effects, relative to those in gas turbines, of fuel-oil ash in free-piston gasifiers.

See also

H. W. SCHAB: 'Bibliography of a Decade of Research on Oil-Ash Corrosion by Heavy Fuels (1948–1958).' *Jnl. Amer. Soc. Naval Engineers*, 1958, vol. 70, Nov., pp. 761–71.

The *bibliography* is introduced by a short survey of the factors involved in residual-oil-ash corrosion, and of research which has been carried out on the subject. This is followed by annotated references to more than 150 items of literature published from 1948 (when the problem of oil-ash corrosion was just beginning to assume serious proportions) to 1958. Several relevant papers written prior to 1948 are also included in the survey. The brief notes indicating the scope of each item are supplemented by designations denoting the field to which the paper mainly relates: gas turbines, steam-power plant, or fundamental research on corrosion.

See also

A paper entitled 'Present Status of the Oil-Ash Corrosion Problem' is to be presented by C. J. Slunder at the 15th Annual Conference of the National Association of Corrosion Engineers, to be held in Chicago in March 1959. No details of the paper are yet available, but as soon as it is published notification will be made in *The Nickel Bulletin*.

Inhibition of Lead Attack by Nickel and Zirconium Additions

The following abstract of a paper to be presented at the 15th Annual Conference of the National Association of Corrosion Engineers is published in *Corrosion*, 1959, vol. 15, Jan., p. 84.

W. LECHNICK: 'Corrosion-Resistance of High-Nickel-Content Steels to High-Temperature Lead.'

'Corrosion-resistance of nickel-bearing steels in contact with lead at 1400°–1500°F. (760°–815°C.) was enhanced when nickel and zirconium were added to the lead. Materials were tested under static conditions for 340 to 5,252 hours.

'Test procedures and methods used to purify lead are described. Data on rates of corrosion, with and without inhibitors, are presented. Results of microscopic examination of test specimens are included.'

(If and when this paper is published notification will be made in *The Nickel Bulletin*.)

Elastic Modulus of Austenitic Stainless Steel

L. F. VOSTEEN: 'Effect of Temperature on Dynamic Modulus of Elasticity of Some Structural Alloys.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 4348, Aug. 1958; 19 pp.

Effect of temperature on Young's modulus of elasticity was determined for two aluminium alloys, a magnesium alloy, a titanium alloy, and a free-cutting 18–8 chromium–nickel steel (A.I.S.I. Type 303). The method used consisted in vibration tests on beam specimens, at intervals from room temperature to 900°F. (482°C.). Test frequencies were varied from 40 to 550 cycles per second. The results are compared with values of moduli obtained by conventional stress/strain tests.

It was found that dynamic modulus decreases with rise in temperature, but that the fall is not so rapid as that occurring in conventional stress/strain conditions. It is shown that the difference between the dynamic and the static moduli is due to internal-friction effects, and cannot be attributed to the influence of creep.

High-Nickel Alloys Resistant to Hydrochloric Acid, Hydrogen Chloride and Chlorine

HENRY WIGGIN AND CO., LTD.: 'Wiggin High-Nickel Alloys *v.* Hydrochloric Acid, Hydrogen Chloride and Chlorine.'

Publn. 1530,* Oct., 1958; 51 pp.

Nickel and high-nickel alloys are among the few metallic materials which exhibit satisfactory resistance to hydrochloric-acid solutions. Selection of the most suitable material for a specific application will be governed by the concentration, aeration and temperature of the acid, and by such factors as acid velocity, film formation, continuity of exposure, permissible metallic content of the solution, and the physical and mechanical properties of the material itself.

In the first part of the publication these factors are discussed in relation to the corrosion-resistance of the following materials: nickel, 'Monel', 'Inconel' and 'Corronel B'. The second part of the brochure is concerned with evaluation of the resistance of the same materials to attack by hydrogen chloride and chlorine at ambient and high temperatures. The last section summarizes the results of industrial experience and plant corrosion tests in fields involving exposure to hydrochloric acid and halogens: e.g., chlorinated hydrocarbon solvents, organic and inorganic chlorides, corrosives encountered in the production of synthetic resins and rubbers, solutions used in the pickling of iron and steel, and corrosive media encountered in petroleum refining and in the manufacture of pulp and paper.

The information given is supplemented by extensive tabulated data on the corrosion-resistance of the materials under the various conditions discussed.

Passivity in Metals: International Colloquium

'Proceedings of the International Colloquium on Passivity of Metals, Heiligenberg bei Darmstadt, Sept. 1957.'

Zeitsch. f. Elektrochemie, 1958, vol. 62, No. 6–7, pp. 619–827.

Report of Conference jointly convened by The

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Electrochemical Society, Die Deutsche Bunsen-Gesellschaft für physikalische Chemie and The Faraday Society.

The thirty-three papers contained in this volume came from authors in many countries and were representative of recent work and current views on various aspects of the subject. The general relation of the phenomenon of passivity to nickel-containing materials is obvious, but space considerations preclude a detailed record in *The Nickel Bulletin*. Reference is, however, given below to some papers which specifically report work on nickel and its alloys.

Y. M. KOLOTYRKIN: 'Electrochemical Behaviour and Anodic Passivity Mechanism of Certain Metals in Electrolyte Solutions', pp. 664–9.

H. H. UHLIG: 'Electron Configuration in Alloys and Passivity', pp. 700–7.

N. A. NIELSEN and T. N. RHODIN: 'Passivity of Stainless Steel', pp. 707–16.

N. D. TOMASCHOW: 'The Passivity and Corrosion-Resistance of Stainless Steels', pp. 717–29.

C. CARIUS: 'Passivity of 18–8 Chromium-Nickel Steels in Sulphuric Acid and Distilled Water, as Characterized by Time/Potential Curves', pp. 730–3.

W. P. MCKINNELL, R. SPEISER, M. G. FONTANA and F. H. BECK: 'The Sorption of Some Diatomic Gases on Stainless Steel and Iron Surfaces and its Relation to Passivity', pp. 733–9.

K. SCHWABE and G. DIETZ: 'The Passivity of Nickel', pp. 751–9.

R. PIONTELLI and G. SERRAVALLE: 'A Contribution to the Knowledge of the Passivation and Passivity of Nickel. Part I, Aqueous Solutions', pp. 759–72.

R. PIONTELLI, U. BERTOCCI and G. STERNHEIM: 'Contribution to the Knowledge of the Passivation and Passivity of Nickel. Part II, Pyridine and Fused Salts', pp. 772–5.

G. OKAMOTO, H. KOBAYASHI, M. NAGAYAMA and N. SATO: 'Effect of Temperature on the Passivity of Nickel', pp. 775–82.

Pitting Corrosion

(1) N. D. GREENE and M. G. FONTANA: 'A Critical Analysis of Pitting Corrosion.'
Corrosion, 1959, vol. 15, Jan., pp. 25t–31t.

The authors point out that pitting corrosion probably ranks as second only to stress-corrosion cracking in destructive power and in its insidious nature. The practical importance of preventing pitting attack is generally recognized, but difficulties in studying this type of corrosion have militated against development of a clear conception of the mechanism of such failure.

In this paper a critical analysis is made (on the basis of modern electrochemical and corrosion theories) of the experimental techniques used by various investigators, and of outstanding results and conclusions. The main emphasis is on pitting as occurring in stainless steels, but most of the conclusions drawn are applicable also to the pitting corrosion of other metals and alloys. The study reported was sponsored by the Alloy Casting Institute: the survey covered the literature of the past 35 years, and the report is based on a selected *bibliography* of 95 papers falling approximately within that period.

The discussion is presented in the following sequence:

1. General Aspects of Pitting
   Definition and broad nature of pitting attack
2. Factors Influencing Pitting
   Metallurgical factors: composition of aggressive media
3. Loci and Distribution of Pitting
4. Electrochemical Aspects
   Cathodic and anodic reactions: electrochemical control
5. Theories of Pitting Corrosion
   Critical discussion of the validity of the imperfection, peptization, penetration, adsorption, acid, and ion-exchange theories
6. Other Theories and Concepts
   Magnetic theory, screening effects
7. Initiation-and-Growth Concept
8. Methods used in Study of Pitting Corrosion
   Visual observation, quantitative measurement of attack, potential studies, impressed-current studies, study of pits artificially produced, chemical-indicator studies

Consideration of the available data reviewed in the respective sections leads the authors to the following broad conclusions.

'1. Definitions and terminology used in describing pitting attack are ambiguous in many instances. Pitting corrosion has not been defined or characterized adequately.

'2. Pit sites appear to be almost randomly distributed in relation to metal-surface structure, with some preference for grain and twin boundaries. Pit sites are not random with respect to each other, because of interaction effects.

'3. Pitting-corrosion behaviour can be related to the particular cathodic reaction which occurs during attack. Pitting in systems where oxygen reduction is the major cathodic reaction demonstrates marked differences from attack in systems in which metal-ion reduction is the controlling cathodic reaction.

'4. The concepts of polarization and electrochemical control will probably have to be modified when applied to pitting corrosion.

'5. There are no completely satisfactory theories of pitting corrosion.

'6. The application of artificial-pit techniques to the study of pitting corrosion has not been exploited

completely. (See, however, papers referred to in the following abstracts.)

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(2) N. D. GREENE and M. G. FONTANA: 'An Electrochemical Study of Pitting Corrosion in Stainless Steels. Part I, Pit Growth.'

Ibid., pp. 32t-8t.

This paper also covers part of the work undertaken under A.C.I. sponsorship, *see* preceding abstract. The earlier discussion of the advantages and limitations of using artificial-pit methods included reference to apparatus and procedure used by other investigators who had employed that technique. The present paper describes a different form of (stainless-steel) artificial-pit specimen, which is claimed to permit a unique experimental approach to study of the problem. The new specimen is described (with four figures illustrating design and operation), and test technique is fully recorded.

The steels used (in wire and sheet form) were 18-8-chromium-nickel (A.I.S.I. Type 304) and molybdenum-containing 18-8 (A.I.S.I. Type 316), and the corroding media used included 0·1 molar solutions of ferric bromide, ferric chloride, ferric perchlorate, ferric sulphate, sodium bromide, sodium chloride and sodium nitrate. Variables studied, as affecting susceptibility to pitting corrosion, were as follows: composition of the solution, agitation, atmosphere, interruption of corrosion current, chloride-ion concentration, and inhibitor additions. Results are graphically recorded, with discussion of the influence of the respective factors.

The observations made show that pit growth of 18-8-chromium-nickel steel in ferric-chloride solution is characterized by an early erratic stage, followed by a period of steadily increasing rate of growth. Pit growth is largely controlled by the concentration of chloride ions within the pit cavity and of ferric ions in the corrosive solution.

The results obtained confirmed the autocatalytic nature of pitting.

In ferric-chloride solutions (and possibly in the presence of high-conductivity corrosives which cause pitting) there is negligible interaction between two closely spaced isolated pit sites: such interaction occurs only on densely pitted surfaces.

It is concluded that nitrate ion, studied as an inhibitor of pitting, prevents such attack only when present prior to the beginning of pit growth or possibly during the early stages of pitting. Actively growing pits are stimulated by nitrate-salt additions, except when present in high concentration.

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(3) N. D. GREENE and M. G. FONTANA: 'An Electrochemical Study of Pitting Corrosion in Stainless Steel. Part II. Polarization Measurements.'

Ibid., pp. 39t-44t.

This third paper completes the authors' report on their investigations of the nature of pitting, in which particular interest centred on the phenomenon as observed in austenitic stainless steel of 18-8 chromium-nickel types.

The experiments described in this section of the report were carried out with the apparatus referred to in the preceding paper, modified to give additional facilities for study of pitting inertia and other factors which had been found to merit closer investigation. The corrosive used consisted of 0·2-molar ferric chloride stabilized with 0·05-molar HCl.

On the basis of the pit-growth and polarization experiments, details of which are given, the authors' present an analysis of electrochemical action during pitting.

The experience obtained during this work, and the observations made, indicate that in order completely to describe pitting attack it is necessary to have an infinite series of rapid or instantaneous polarization diagrams, since ordinary polarization curves are not applicable to this type of corrosion. It is concluded that the concept of electrochemical control must be modified when applied to pitting corrosion. The autocatalytic nature of pitting corrosion was still further clarified. Pitting corrosion produces self-stimulating electrochemical changes at both the anode and the cathode areas.

It is demonstrated that in ferric-chloride solutions the negligible interaction between two closely spaced isolated pits is caused by uniformity of cathodic current distribution and the weak polarization of the metal surface surrounding the pit sites.

Underground Corrosion of Metals: Review

'Underground Corrosion. A Summary of 45 Years of N.B.S. Research.'

Corrosion, 1959, vol. 15, Jan., pp. 107-10.

Research on the corrosion of underground structures has been in progress at the National Bureau of Standards since 1910, and the results have built up a steadily growing understanding of the factors involved in underground exposure. This in turn has led to development of increasingly efficient methods of preventing deterioration of buried metals.

The results of field-exposure tests and of laboratory investigations have recently been reported in *N.B.S. Technical Report* 2209. This summary of the work done includes reference to periodic reports which have been issued on various sections of the research. For a comprehensive survey of the work of the Bureau in this field attention is directed to *N.B.S. Circular* 579, published in 1957 by the U.S. Government Printing Office, Washington, D.C., price $3.

Intergranular Corrosion of Austenitic Stainless Steels in Petroleum Refineries

'Four Case Histories: Intergranular Corrosion of Austenitic Stainless Steel in Petroleum Refineries.'

Corrosion, 1958, vol. 14, Dec., p. 121.

Causes and prevention of intergranular corrosion are discussed in relation to specific cases of failure

which have been reported in 18-8 chromium-nickel steels used in the applications indicated below.

Furnace tubes of straight chromium-nickel steel (A.I.S.I. Type 304), used in a thermal cracking plant.

Pipe lines of molybdenum-containing 18-8 (A.I.S.I. Type 316) in a fixed-bed catalytic re-forming unit.

Linings of Type 316 steel, in pressure vessels handling phosphoric acid.

A vessel of Type 316 steel used to handle organic acids.

Stress-Corrosion Cracking of Austenitic Stainless Steel in Dilute Caustic Solutions

P. P. SNOWDEN: 'Intercrystalline Stress-Corrosion Cracking of Austenitic Stainless Steel in Caustic Solutions.'

Chemistry and Industry, 1958, No. 51, Dec. 20, p. 1692.

Cases of intercrystalline failure of austenitic steel exposed to concentrated caustic solutions have been reported by WANKLYN and JONES and by EDELEANU (for relevant abstracts see *Nickel Bulletin*, 1958, vol. 31, No. 11, p. 302; 1959, vol. 32, No. 1, p. 22). In this note the author refers to further experience with the same type of failure, giving results derived from investigation of the stress-corrosion behaviour of stainless steel in potassium - hydroxide and sodium - hydroxide solutions at high temperatures.

It was found that in both solutions cracking was intercrystalline (in contrast to the *trans*crystalline nature of failures previously reported in stainless steels exposed to sodium hydroxide in high-pressure steam). Failure was rapid with caustic solutions as dilute as 1 per cent. by weight, and at 300°C. and a stress of 10 tons/sq. in. (16 kg./mm.^{2}) fracture could occur in a few hours. Steel specimens exposed to high-pressure steam contaminated with potassium hydroxide failed intergranularly, and further tests showed that cracking resulting from attack by high-pressure steam containing sodium hydroxide could be induced to follow an almost entirely intercrystalline course by addition of sodium silicate.

Variation of the test conditions did not affect the mode of attack when the corrosive was in solution, though with the more dilute sodium-hydroxide solutions small localized areas of transcrystalline attack were found. Reduction in any one of the main variables (stress, concentration of the solution, and temperature) was accompanied by reduction in the rate of attack, but complete immunity was achieved only by reduction in all three.

Microscopical examination of the stainless steel (which was not susceptible to cracking in the usual intercrystalline-corrosion test solutions), revealed no metallurgical feature to account for the attack. It is tentatively suggested, however, that it might be attributable to a sub-microscopic grain-boundary phase which, under certain conditions, adopts a potential at which rapid corrosion occurs. If such is the case, it might be possible to eliminate susceptibility to intercrystalline cracking by appropriate heat-treatment, to disperse the phase.

Resistance of Titanium-Stabilized Austenitic Steels to Corrosion by Nitric Acid

J. M. WEST: 'Nitric-Acid Corrosion of Austenitic Stainless Steels.'

Jnl. Applied Chemistry, 1959, vol. 9, Jan., pp. 1-10.

It has been found that exposure to temperatures in the ranges 600°-750°C. and 1300°-1400°C. seriously impairs the resistance, to nitric acid, of 18-8 chromium-nickel steels, despite effective 'stabilization' with titanium. Since the corrosion rates of steels so sensitized can be dangerously high, considerable work has been done to establish the conditions necessary for accurate determination of the resistance of titanium-stabilized steels to nitric acid under varying conditions. The results of one such investigation, by HEELEY and LITTLE (*Jnl. Iron and Steel Inst.*, 1956, vol. 182, Mar., pp. 241-55; abstract in *Nickel Bulletin*, 1956, vol. 29, No. 6, p. 115) led the author to carry out the experiments now reported.

HEELEY and LITTLE, in a systematic investigation, had used a test technique which differed in many respects from that employed in similar (unpublished) work by CLARK and CONNOLLY. The results of these two investigations showed some disagreement, and in an attempt to determine the relative validity of the two test techniques, the author carried out comparative experiments on specimens of 12 steels, using (A) procedure closely similar to that employed by HEELEY and LITTLE, and (B) the method used by CLARK and CONNOLLY. Details of the two methods are given below.

'*Technique A.* Abraded specimens were laid singly in 400-ml. flasks containing 200 ml. of acid (so that the solution-volume/specimen-area ratio = 10·6 ml./cm.^{2}). The flasks were immersed in boiling water, each being fitted with an open air-condenser some 18 in. (45 cm.) long. At approximately weekly intervals throughout a test lasting 36 days specimens were weighed and the corrodent was replaced by fresh acid. By this means a check was kept on the appearance and progressive weight-loss of each specimen, and soluble corrosion products were prevented from accumulating.

'*Technique B.* Pickled specimens were tested in batches of six (presenting a total area ~ 114 cm.^{2}) hung from glass 'trees' in 2-in. (5-cm.) diameter test-tubes containing 340 ml. of acid (solution-volume/specimen-area ratio = 3·0 ml./cm.^{2}). Each test-tube was immersed in a 4 : 1 glycerine-water bath maintained at 125°C. (the boiling point of the acid was about 110°C.) and was closed by means of a water-cooled 'finger'-type condenser. Specimens were weighed only before and after the test period of 50 days, to obtain a figure for the mean corrosion rate in the boiling acid. In a few instances, where a different mode of heating was used, some acid was lost periodically owing to bumping: fresh acid, rather

than water, was used to make up this loss, since direct evaporative losses were small.'

Eleven 18-8-Ti steels and one of 18-8-Mo-Ti type (varying in effective Ti:C ratio) were selected for test, in 30 per cent. nitric acid. The influence of sensitization was determined by subjecting three sets of four specimens from each steel to one of the following heat-treatments: (*a*) ½ hour at 1050°C., water-quench; (*b*) ½ hour at 1050°C., water-quench + 2 hours at 650°C., air-cool; (*c*) ¼ hour at 1050°C., air-cool, + 2 hours at 650°C. The effects of variation in preparation of the surface prior to testing were taken into account by abrading two specimens from each set with '280' emery paper, and subjecting the remaining two to a double pickling treatment which gave a rough surface. Weight losses were converted to a penetration rate expressed in terms of mm./year.

Corrosion-rate/time curves are presented for steels tested by Technique A, and the 'long-term' rates derived by use of Technique B are tabulated, for comparison with equivalent data extrapolated from the 'progressive' corrosion rates obtained by Technique A. Reproducibility of results was much better with test A than with test B.

To confirm the validity of the results obtained with Technique A, further experiments were made with sensitized specimens of the steel which had exhibited the highest rate of corrosion. The effect of the following variables was studied: (*a*) daily weighing with change of acid; (*b*) daily weighing, leaving the acid unchanged for 40 days, (*c*) daily weighing from the 18th day onward, leaving the acid unchanged, and (*d*) daily weighing without removing the loose deposit which forms during testing. The data obtained indicated that the ultimate corrosion rate was substantially unaffected by variation in the method of weighing and was equal to the extrapolated 'progressive' corrosion rates determined in the main experiments.

The relevance of the two tests to conditions obtaining in nitric-acid plants is critically discussed. It is concluded that 'Techniques A and B yield different assessments of susceptibility, although it is possible that if Technique B were suitably modified (e.g., by testing specimens separately while maintaining the same solution-volume/surface-area ratio), this difference would be less marked. The choice between the techniques is then contingent on which test is the more able to show small differences in corrosion behaviour. Higher strengths of acid than 30 per cent. seem to distinguish such differences less readily, and Technique A is probably to be preferred on this account.

'As far as assessing suitability for plant use is concerned, an abraded finish might be criticized on the grounds of giving a surface with a highly complex and indeterminate structure, unrepresentative of 18-8-Ti plate as normally provided by the manufacturer. On the other hand, a pickled finish applied *after* a sensitizing heat-treatment is no more representative of service conditions than an abraded one, and gives a surface which already shows some intergranular and ferrite-phase attack which differs greatly from steel to steel. The experiments with daily weighings demonstrate, however, that the initial surface condition is immaterial for tests lasting longer than 20 days. It is sufficient merely that the final stage of specimen preparation should be accurately reproducible, in which case, on grounds of uniformity, the abrasion treatment is probably rather better than pickling.'

The respective techniques provide results which are relevant to very different plant conditions. Technique A reflects those in which corrosion products (gaseous and ionic) are continuously removed, e.g., as in a pipeline, or a vessel in which a liquid is vigorously stirred. Technique B, a more stringent method of test, is relevant to conditions in which the acid is boiling or near-boiling, and in which the corrosion products are not readily removed. Stock tanks are used to store only relatively cold acid, whilst concentrated stills (in which the acid is boiling) do not allow an accumulation of corrosion products. The only place likely to satisfy both criteria is a position in which hot acid is static in recesses or valves. Since in correctly designed plant such conditions do not exist, it must be concluded that Technique B is not commercially applicable to practical testing in relation to plant practice. It is suggested that the effects of sensitization at 650°C. would be better revealed by Technique A if the 'cumulative' rates were taken as a criterion of corrosion-resistance rather than the overall weight loss as used by HEELEY and LITTLE.

The conclusions drawn with respect to the relative corrosion-resistance of the steels tested are summarized as follows:

'(1) 18-8-Ti steels having 0·06 per cent. carbon or less are not markedly susceptible to the '650° effect' and are unlikely to corrode at rates exceeding 0·1 mm./year in 30 per cent. nitric acid.

'(2) Steels having 0·06–0·10 per cent. carbon are usable for nitric-acid duty so long as the titanium/carbon ratio lies between 6·0 and 7·2 (allowing for nitrogen content).

'(3) Steels having carbon contents greater than 0·10 per cent. are usable if the titanium/carbon ratio is in the region of 5·5, there being a narrow band of passable ratios which depend on the carbon content.

'(4) The corrosion rate of sensitized steels rises rapidly in the first fortnight or so of testing, and it is suggested that the subsequent steady rate is determined by the thickness of a layer of exfoliated material dissolving at its outer surface as fast as it is formed.'

Resistance of Steels to Acid-Contaminated Cooling Water

R. J. SCHMITT: 'Behaviour of Carbon and Stainless Steels in Acid Waters.'

Corrosion, 1958, vol. 14, Oct., p. 445t.

The service life of carbon-steel condenser tubes is governed by the degree of contamination of the

cooling water. Where the water is contaminated by acid drainage no possibility exists for deposition of the protective scale from which such steels derive their corrosion-resistance in fresh water. This factor, and the need for selection of a material the corrosion-resistance of which bears a direct relationship to the specific operating conditions, are emphasized in the present article.

The case-history described concerned the failure of carbon-steel condenser tubes used in the wash-oil-regenerating system of a coal/chemical plant. (The wash-oil condenser receives both liquid and vapour wash oil from a Dowtherm heat exchanger which partially condenses the oil vapours coming from the wash-oil still. The temperature of the oil is in the region of 350°F. (175°C.); the cooling water enters the condenser at about 80°F. (27°C.) and leaves at about 180°F. (85°C.).) The cooling water used is contaminated with acid drainage from old coal mines and, since the water is not re-circulated, treatment other than by addition of lime, to raise the pH from about 3·8 to 4·5, would be uneconomic. Under these conditions the carbon-steel tubes corroded severely and failed after about four months' service.

To reduce the high maintenance and replacement costs involved, plant tests were carried out to compare the performance of four carbon-steel tubes and four tubes of 18-8 chromium-nickel stainless steel (A.I.S.I. Type 304), installed in the tube bundle of the condenser at the same time. After four months' exposure the carbon-steel tubes failed as a result of severe pitting. Two of the stainless-steel tubes, which were removed from the condenser after a similar period, were practically unaffected and marks made during fabrication operations were still present on their surface. The other two tubes will be removed after a year's exposure. As a result of these satisfactory tests in the low-pH river water, the whole condenser is to be equipped with stainless-steel tubes.

Resistance of Stainless Steel and Electrodeposited Nickel Coatings to Attack by Detergents

A. BUKOWIECKI: 'Investigations into the Corrosive Effect of Detergents.'

Schweizer Archiv, 1958, vol. 24, Nov., pp. 335-70.

The increasing use of detergents in washing machines and similar equipment has aroused considerable interest in the degree to which the individual detergent is corrosive and in the relative corrosion-resistance of conventional materials of construction. The Eidgenössische Materialprüfung- und Versuchs-anstalt, Zürich, has recently carried out research on both aspects of the subject. Four procedures were finally evolved: (1) for study of the corrosive behaviour of the detergent; (2) for assessment of the corrosion-resistance of materials of construction, using, as a criterion, their relative resistance to 'standard' detergents; (3) for determination of the corrosive effect of such steeping agents as bleaching soda; and (4) for assessing the suitability of materials for steeping vessels. Particulars of the procedures and of the standard detergents are given in appendices to the present paper. The author's principal concern is, however, with presentation of the results of a systematic investigation of the characteristics of the standard detergents and their individual constituents, and with discussion of the findings obtained from corrosion tests on various metallic materials, including chromium-nickel stainless steel and electro-deposited nickel coatings. The tests were carried out mainly under static conditions.

The principal conclusion reached was that severest corrosion could be attributed to the combined effect of polymer phosphates and sodium perborate, while soap and other constituents of modern washing detergents are only mildly corrosive and can even act as inhibitors. Of the materials tested, galvanized steel and an aluminium alloy, 'Peraluman', proved particularly susceptible to attack, but chromium-nickel stainless steel and nickel-plated copper and brass were found suitable for use in contact with detergents. Tests were made also to determine the effects of exposing, to the test solutions, various combinations of metallic materials in the form of galvanic couples, and to assess the degree to which electrodeposited and enamelled coatings confer corrosion-resistance on the basis metal.

Stainless Steel in Architecture

V. N. KRIVOBOK and R. E. PARET: 'Stainless Steel in Architecture in the U.S.A.'

Centre d'Information du Nickel, Paris, Publn. X-35, 1958; 36 pp.

The brochure opens with notes on the properties of chromium-nickel stainless steel which are of interest in the architectural field, drawing particular attention to the economic advantages resulting from reduced maintenance costs and to the pleasing appearance obtained by the use of this steel, either alone or in association with other architectural materials. The second section reviews the purposes for which stainless steel may be used, externally in actual building construction and curtain walling, and internally in numerous hardware and furnishing accessories. Illustrations typical of a wide range of applications demonstrate the versatility of stainless steel for use in office, domestic, hospital, laboratory and other buildings.

Later chapters contain information of direct interest to architects in relation to design of buildings and accessories in which stainless steel is incorporated. This section of the brochure contains numerous diagrams (in many cases scale drawings) showing details of exterior and interior construction.

The following items are also of interest in this connexion:

'Economy and Beauty—Two Reasons for Increased Use of Stainless Steel Curtain-Wall Construction.'

INCO MAGAZINE, 1959, vol. 27, Jan., pp. 8-9.

Illustrated notes on several large buildings, in

various American cities, in which use has been made of nickel-chromium stainless steel in curtain-wall and other architectural applications.

'New Doors for Home Owners.'

Ibid., pp. 28–9.

Illustrations of two models of stainless-steel doors placed on the market by Challenger Products, Inc., Carnegie, Pa. The average door contains about 40 lb. (18 kg.) of the steel.

Permissible Internal Pressures for Stainless-Steel Tubing

W. O. NUSSEAR: 'Tubing Tables Include Corrosion Factor.'

Petroleum Refiner, 1958, vol. 37, Nov., pp. 271–2.

Advantage is taken of the excellent corrosion-resistance of 18-8 chromium-nickel stainless steel of A.I.S.I. Type 304 in many refinery applications. Some corrosion is, however, inevitable, and in design of plant for high-pressure applications the effects of corrosion, in terms of decrease in wall thickness, should be taken into account, together with slight variation in wall thickness within the limits of commercial tolerance. The allowance in wall thickness necessary to cover both variation within the dimensional tolerance to which the tube is produced and loss of metal by corrosion has been expressed in a formula which allows determination of permissible internal pressures for various sizes of small-diameter tubing. (The corrosion allowance for all gauges of Type 304 stainless-steel tubing is assessed at 0·015 in. (0·375 mm.); commercial tolerance with respect to small-diameter cold-drawn tubing is ± 10 per cent.)

The relevant formulae are given in this article, in conjunction with two tables listing (1) permissible internal pressures and theoretical bursting pressures, at 100°F. (38°C.), for tubing of various diameters and wall thicknesses; (2) factors which permit calculation of maximum permissible pressures at temperatures ranging from 100° to 1200°F. (38° to 650°C.).

The article includes references to pertinent A.S.T.M. specifications and a brief review is given of the advantages of tubing *vis-à-vis* pipe.

Recovery Treatment for Graphitically Embrittled Nickel

See abstract on p. 71.

Bright Annealing Furnaces and Ancillary Equipment

See abstract on p. 71.

Welding of Nickel and High-Nickel Alloys

(1) J. HINDE: 'Welding of Nickel and High-Nickel Alloys in the Chemical Industry.'

International Inst. Welding, 1958 Annual Assembly, Vienna: *Preprint*, 8 pp.

Some indication of the extensive use of nickel and nickel-base alloys in chemical plant is given by illustrations of some typical applications in widely varying industries. The significance of correct welding technique, as a factor affecting service behaviour, is emphasized, and practical recommendations are made on procedure which will ensure soundness, adequate mechanical properties, and a high degree of corrosion-resistance in welded joints.

The materials considered are nickel (of the low-carbon grade required for chemical plant), nickel-copper alloy ('Monel' type), nickel-molybdenum, nickel-molybdenum-chromium and nickel-molybdenum-chromium-iron alloys. Typical compositions are given, and properties significant in relation to welding are tabulated for these materials in the annealed condition, i.e., the condition in which they are welded. Notes on the welding techniques which may be used for the respective materials are supplemented by a table showing compositions and standard A.W.S./A.S.T.M. and B.S. classifications of filler wires and electrodes. Throughout the paper emphasis is laid on the practical aspects of welding, e.g., cleanliness in preparation of the parent material, design of joint, maintenance of suitable welding conditions, removal of welding fluxes, etc.

The second section of the paper is concerned with the use of clad steels, linings and overlays. Welding sequences for joining clad steels are diagrammatically illustrated and precautions required in welding the composite materials are reviewed, including reference to the problem of iron dilution. Joint design for strip lining is discussed and illustrated, and reference is made to lining by the overlay technique. Attention is directed also to recent developments in nickel-on-steel sheet on which the coating is produced by electrodeposition or by the electroless process.

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(2) R. P. CULBERTSON and R. C. PERRITON: 'Welding of High-Nickel Alloys for Chemical Plant and Equipment.'

International Inst. Welding, 1958 Annual Assembly, Vienna: *Preprint*, 8 pp.

This paper deals specifically with the welding of four alloys of nickel base, containing, respectively; molybdenum, molybdenum + chromium, molybdenum + chromium + iron (available in both wrought and cast form), and silicon (available in cast form only). The main characteristics of these alloys are summarized, an indication is given of their uses in chemical plant, and welding procedures are recommended for the respective materials. Sections of the paper are concerned with welding of solid materials, liner welding, joint design for lining *in situ* or before installation, and testing of lined vessels and solid welded joints.

The paper is copiously illustrated with diagrams and tables, and with photographs showing applications in which the alloys discussed have been used in solid or in clad form.

Welding of Ferritic to Austenitic Steel Tubing

B. LÖFBLAD and G. LINDH: 'Development of a Method for Welding Ferritic to Austenitic Superheater Tubes in Steam-Power Plants.'

International Inst. Welding, 1958 Annual Assembly, Vienna: *Preprint*, 10 pp.

Welding of ferritic to austenitic steel introduces two well-recognized problems: (1) the risk of carbon pick-up by the austenitic steel from the ferritic type, with consequent deterioration in properties of the high-alloy material; (2) the difference in coefficients of thermal expansion of the two materials. As an introduction to the report of their own work, the authors refer to methods which have been proposed for overcoming these difficulties. (Reference is given to original reports on the respective procedures.)

The experimental work described consisted of comprehensive tests on the thermal-expansion characteristics of (1) chromium-molybdenum steel of the type most used for tubing in power plant; (2) austenitic chromium-nickel steel of the composition generally employed for sections of power-plant piping working under higher-temperature conditions; and (3) alloys which would give thermal-expansion coefficients intermediate between those of the ferritic and the austenitic materials which must be joined. The tests cover temperature ranges involved in welding, within which differential expansion would be liable to set up internal stress.

The results led to development of a method involving the use of a weld material comprising an alloy containing nickel 80, chromium 3, carbon 0·07 per cent. with at least 0·7 per cent. niobium, balance iron, which has a coefficient of thermal expansion intermediate between the values characteristic, respectively, of the ferritic and the austenitic materials which are to be joined.

Test data demonstrate the reduction of stress effected by the use of this method, and photomicrographs of welds after long-time annealing indicate the inhibition of carbon diffusion obtained by employing the high-alloy stabilized weld metal. The report includes results of tensile tests at room temperature and of stress-rupture tests at 600°C.

Clad Steel, Liners and Overlays in the Chemical Industry

L. CAPEL and C. NEDERVEEN: 'Use and Application of Clad Steel, Metallic Liners and Overlay Deposits in the Manufacture of Vessels for the Chemical Industry.'

International Inst. Welding, 1958 Annual Assembly, Vienna: *Preprint*, 14 pp.

This paper is designed to present information and make recommendations, based on some practical experience, with regard to conditions in which clad steel liners and overlays may provide a technically adequate and economic solution of some of the corrosion problems encountered in various branches of the chemical industry.

(1) *Clad Steel*

Difficulties associated with the varying thermal-expansion properties of the basis and cladding metals are discussed, and the welding of clad steel is dealt with in some detail, as exemplified by stainless-clad. Welding sequence is well illustrated. Suitable welding electrodes are listed, and methods which may be adopted to prevent weld cracking are reviewed. Thermal treatment of welded clad steel is considered in relation to the nature of the base metal and of the cladding, the thickness of the base metal, and deformation which may occur during fabrication of the vessel.

(2) *Metallic Liners, consisting of Strips or Sheets of Corrosion-Resistant Material*

Methods of lining are illustrated, some typical examples of their use are cited, and procedure for application and welding of liners is described. Thermal treatment is discussed from the point of view of selecting conditions which will not be unduly unfavourable to either component of the deposit. In this connexion, however, it is recommended that, wherever possible, lining should be by a method which permits heat-treatment of the outer wall of the vessel prior to installation of the liner.

(3) *Overlay Deposits*

The scope of application of this method of protection is outlined, and methods which may be used to deposit overlays are briefly discussed. For deposit welding it is customary to use one of the following procedures: (1) manual welding with covered electrodes, (2) inert-gas metal-arc welding, and (3) submerged-arc welding. The advantages and limitations of these methods are considered, particular reference being made to 'Unionmelt' welding.

The major requirements which must be satisfied by an overlay deposit (complete fusion with the basis metal and between individual layers of the weld metal, coupled with adequate corrosion-resistance) are considered, as affected by conditions of deposition of the weld metal, its composition, and the electrode used. Some recommendations are made with regard to post-deposition stress-relief treatment.

A feature of the paper is the large number of detail drawings and other illustrations.

Stainless-Steel Overlays in Sulphate Digesters

F. SCHNEIDER AND R. J. WALKER: 'The Automatic Stainless-Steel Overlay of Sulphate Digesters.'

International Inst. Welding, 1958 Annual Assembly, Vienna: *Preprint*, 8 pp.

In the pulp and paper industry corrosion of sulphate digesters has in recent years become a serious problem. Accelerated corrosion has been experienced by most paper mills to a point at which replacement of the digesters or reduction in operating pressure is called for after a relatively short service life. This intensification of corrosive attack is attributed mainly to the use, under modern conditions, of

shorter cooking cycles, together with stronger liquors which are usually higher in sulphide concentration than those normally employed.

In repairing affected digesters, many methods have been used: nine are listed as being currently under test. Among the various procedures the 'alloy weld deposit or overlay' method has shown considerable promise, and following successful results with manual-arc application (using the shielded- metallic-arc process as a means of protecting localized severely corroded areas) an automatic overlay method, employing inert-gas-shielded metal-arc welding, has been developed, to provide complete overlaying of the digesters. This automatic method, using an austenitic stainless steel as the coating material, was developed during 1955 at the Weyerhaeuser Timber Company, Longview, U.S.A. The overlay consists of successive circumferential beads deposited in the horizontal position by means of a rotating jig which automatically propels the welding gun round the inside of the digester. The appearance of a typical overlay so produced is illustrated in this paper.

The authors, who are associated with Canadian Liquid Air Company, Ltd., describe the adaptation of this method for protection of digesters in the plant of Marathon Corporation of Canada, an important paper-making firm. The stages of development were as follows:

Laboratory tests with inert-gas-shielded metal-arc equipment were planned—

(1) to develop a satisfactory welding procedure which would provide a smooth overlay approximately $\frac{1}{8}$ in. (3 mm.) in thickness, at a high rate of deposition and with controlled penetration,

(2) to obtain preliminary cost data,

(3) to determine which type of austenitic stainless steel would be most suitable from the technical and economic standpoints.

Test procedure is described, with notes on penetration effects and dilution of the overlay by the base metal. Tests of filler wires of three types of austenitic steel (25-20, 25-12 and 18-12-2·5Mo chromium-nickel steels) proved that only the 25-20 type yielded satisfactory composition in the overlay deposit. A test patch of this type was fitted into a corroded digester (procedure is diagrammatically illustrated and costs are discussed), and examination of the patch after 18 months' service revealed so slight a degree of corrosion that annual loss was estimated at only 0·003 in. (0·075 mm.) per year.

These findings resulted in adoption of the overlay method for the seven sulphate digesters in the Marathon plant. A description is given of welding equipment and procedure used for the large-scale overlaying, which, in the interests of non-interference with output, had to be carried out in the minimum of time per digester. A total overlaying period of about 15 days appears to be average, and there is every indication that the new process will so prolong the life of the digesters as to make the undertaking a success from the economic as well as the technical point of view.

Stainless-Clad Cellulose Digesters

G. ALMQVIST and S.-E. ERIKSON: 'Some Aspects of Welding Stainless-Clad-Steel Cellulose Digesters.' *International Inst. Welding*, 1958 Annual Assembly, Vienna: *Preprint*, 8 pp.

The growing severity of corrosion problems in digesters is emphasized, and the potential technical and economic advantages of using clad steel are indicated. The paper is concerned with procedure used in welding the stainless-steel-clad digester shells: manual, as well as automatic, arc welding is discussed, with details of preparation, joint design and methods used for welding both the base and the cladding.

The authors report experimental work in which a study was made of the behaviour of two weld metals employed in fabrication of a 1-in. (25-mm.) thick clad composite consisting of a base of pressure-vessel steel and a 15 per cent. cladding of a chromium-nickel-molybdenum steel (18-8-2·5 per cent.). The approximate compositions of the weld materials studied are shown below:

The results of tensile tests and microstructural examination of the welds and adjacent areas in joints arc-welded with varying combinations of electrode lead to the conclusion that optimum results are obtained by the following sequence:

(1) Welding the unalloyed (base) steel with an electrode suitable for such steel.

(2) Chipping the root from the clad side.

(3) Welding the root beads of the cladding with niobium-stabilized electrodes which produce a weld metal containing an excess of alloying constituents, to compensate for dilution effects, e.g., using electrodes of the 22-12-3-1 per cent. steel shown in the table below.

(4) Using for the top beads an electrode corresponding in composition to the stainless-steel cladding which is being welded.

Weld Metal	C %	Si %	Mn %	Cr %	Ni %	Mo %	Nb %
22-12-3-1	0·07 max.	0·5	0·5	22	12	3·25	1
19-9-2	0·06 max.	0·6	0·6	19	9	2·5	—

Cladding of Silver/Boron-Carbide Cermets with Stainless Steel

L. LEWIS and J. F. SOPPET: 'Development of a Method for Roll Cladding Silver, Boron-Carbide Cermets with A.I.S.I. 304 Stainless Steel.'

Yankee Atomic Electric Co., Rept. YAEC-59, May 1, 1958; 22 pp.

Previous work on alternative materials for control rods had indicated the advantages of a silver/boron-carbide core clad with corrosion-resisting steel. Strength, radiation stability and heat-transfer characteristics were dependent on the production of a uniform and continuous bond between the cermet and the steel, an objective which it was thought could best be achieved by roll cladding. The upper limit of rolling temperature was 1650°F. (900°C.), i.e., about 50°F. (28°C.) below the melting point of silver. The work was divided into two phases: investigation of techniques suitable for roll-bonding 18-8 (A.I.S.I. Type 304) chromium-nickel stainless steel at 1650°F. (900°C.) or below; application of the most suitable of these techniques to cladding of the cermets. Results were assessed by metallographic examination of the bonded specimens.

It was found that the steel could be roll-bonded to itself at either 1650°F. or 1400°F. (900° or 760°C.). Bonding at 1400°F. resulted in a composite containing large amounts of carbide precipitates; at 1650°F., however, carbide precipitation did not occur and recrystallization was induced across the interface of the bond between the stainless-steel plates. In cladding the silver/boron-carbide cermets, best results were obtained by rolling at 1650°F., starting with a light reduction and proceeding, in subsequent passes, to moderate and heavy reductions.

Welding Chromium-Nickel Austenitic Steels

F. A. BALL: 'Welding Corrosion-Resisting Steels of the 18/8 Cr/Ni Type and Heat-Resisting Steels.'

Reprint from *Sheet Metal Industries*, 1958, vol. 35, June, pp. 439-52; July pp. 509-22.

MOND NICKEL CO., LTD., *Publn.* 1584; 28 pp.

See abstract in *Nickel Bulletin*, 1958, vol. 31, No. 11, pp. 307-8.

Welding of 'Inconel X'

K. M. SPICER and G. R. PEASE: 'Welding of 'Inconel X'.'

The Industrial Atom Tech. Information Service, T.I.D. 8015, Mar. 1958; 11 pp.

Published by *U.S. Atomic Energy Commission, Department of Commerce, Office of Technical Services*, Washington 25, D.C., U.S.A. Price 50c.

This is one of a series of monographs prepared to encourage industrial interest in atomic energy.

The precipitation-hardenable nickel-base alloy 'Inconel X' is characterized by corrosion-resisting properties and mechanical strength (at both normal and elevated temperatures) which make it eminently suitable for use in certain components of nuclear power plants. Composition and typical properties of the alloy are tabulated in this brochure, in comparison with those of regular 'Inconel', from which the 'X' modification was developed.

The authors make practical recommendations on welding procedure, emphasizing the importance of strict cleanliness in preparation for joining. Temperature/ductility relationships are graphically illustrated, and the significance of residual stress, as affecting welding, is discussed, with details of thermal treatments suitable for use during fabrication of 'Inconel X'.

Factors determining selection of welding procedure are considered, with specific reference to the following variables: thickness of the metal, location of the joint, and need for age-hardening response in the welded joint. Brief critical notes, with recommendations, are given on the following techniques, with particular reference to their suitability for welding of this alloy:

(1) *Metal-arc welding* (recommended only for comparatively light-gauge material, say, up to approximately ¼-in. (6-mm.) thick, and for locations in which high joint efficiency is not essential).

(2) *Inert-gas consumable-electrode welding* (not at present recommended for 'Inconel X', but research on its adaptation is proceeding).

(3) *Inert-gas tungsten-arc welding*, using a filler wire of a composition closely similar to that of the parent alloy. (Welds made by this method have shown the highest degree of predictability yet obtained in welding this material and it is the only fusion-welding process currently recommended for applications in which joint efficiencies of more than 80 per cent. are required.)

(4) *Resistance welding*. (The variables involved in the fabrication of 'Inconel X' components by this method are predominantly mechanical adjustments of equipment of adequate capacity. For details of machine settings and other pertinent information, attention is directed to a paper by NIPPES and FISHMAN entitled 'Optimum Spot and Seam Welding for 'Inconel X' ', published in *Welding Journal*, 1954, vol. 33, pp. 1s-14s.)

A considerable amount of information has already been assembled with regard to the strength and ductility of joints in this alloy: typical data, which can form a preliminary basis for design, are summarized in the brochure, but it is emphasized that much more extensive and detailed tests are required before comprehensive values can be given.

Finally, the authors emphasize the inadvisability of attempting to weld 'Inconel X' in other than the annealed condition. 'It is pointless to attempt to weld hardened material if optimum properties are to be developed in the joint. Not only will the heat-affected zone be softened by the welding operation, but the deposited weld metal will also be in the soft condition until it is subjected to an ageing treatment. Also, if the welded unit is subjected to service temperatures in the low-ductility range, cracking will occur.'

Inert-Gas Consumable-Electrode Welding of Steels in Thin Section

See abstract on p. 71.

Identification of Chromium-Manganese-Nickel and Chromium-Nickel Stainless Steels

'Simple Test Identifies Stainless.'

Iron Age, 1958, vol. 182, Nov. 13, p. 147.

The article gives particulars of a simple, rapid test developed by Electro Metallurgical Company for differentiating the low-nickel stainless steels of the A.I.S.I. 200 series from the chromium-nickel stainless steels of the 300 series.

The following are the only chemicals needed: hydrochloric acid (sp. gr. 1·19), nitric acid (sp. gr. 1·42) and sodium bismuthate. Two drops of nitric acid are placed on the specimen, followed by one drop of hydrochloric acid. When the resultant reaction subsides, two drops of water are added and mixed-in with a glass stirring rod. Finally, small amounts of sodium bismuthate are added until dissolution no longer occurs and excess reagent remains. Within 30 seconds to one minute a dark reddish-brown spot will appear on steels of the 200 chromium-manganese-nickel series: the chromium-nickel steels will exhibit a tan spot.

With sheet material it is advantageous to confine the area of the test within an indent, ¼–½ in. (0·6–1·2 cm.) in diameter, made with a blunt-nosed punch. The reaction area can, however, also be restricted by drawing a 1-in. (2·5-cm.) circle with a grease pencil.

ANALYSIS

Determination of Nickel in Cast Iron by Absorptiometric Methods

See p. 72

Rapid Determination of Additives in Bright-Nickel-Plating Solutions

See p. 75

Rapid Determination of Nickel in Brass and Bronzes

See p. 80

Identification of Chromium-Manganese-Nickel and Chromium-Nickel Stainless Steels

See left-hand column.

Corrigendum

Nickel Bulletin, 1958, vol. 31, No. 6. p. 167.

I. B. ELMAN and L. M. DIRAN: 'Cast 9 per cent. Nickel High-Strength Steel for Low-Temperature Service.'

For

'Amer. Soc. Mechanical Engineers, *Tech. Paper* 246',

read

'International Nickel Co., Inc., *Tech. Paper* 246.'

An up-to-date list of addresses of publishers of the periodicals mentioned in The Nickel Bulletin has just been printed and we shall be pleased to send a copy to readers on request.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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